BEEF FLAVOR ATTRIBUTES AND CONSUMER PERCEPTION

A Thesis

by

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ABSTRACT

Levels of positive and negative beef flavor attributes were created by identifying beef cuts that varied in quality grade, pH, and amount of connective tissue, then cooked to 58 °C and 80 °C utilizing a George Forman grill (GF), food-service grill, or Crock-Pot. Trained descriptive sensory attribute panel, consumer panel, and gas chromatography with dual sniff ports (GC-O) were utilized to measure flavor. Fatty acid composition, non-heme iron and myoglobin content, pH, and fat and moisture analysis were determined.

As degree of doneness increased, beef identity increased. High pH *M. Longissimus lumborum* (LM) steaks had less beef identity than USDA Choice (Ch) LM steaks when cooked on the GF to either internal temperature endpoint or grilled to an internal temperature of 58 °C. Choice *M. Biceps femoris* (BF) roasts cooked to 58 °C had a higher beef identity compared to the Se BF roast cooked to 58 °C. Brown/roasted was lower and bloody/serumy was higher when steaks or roasts were cooked 58 °C.

No strong correlations for beef flavor and non-heme iron or myoglobin content were present. Fatty acid composition accounted for ($P < 0.05$) variation in beef flavor. 149 volatile compounds were identified. Fifteen volatiles accounted for 55 percent of consumer overall liking. Principal component analysis showed lower temperatures and/or shorter cooking times favor the generation of lipid-degradation products, while higher temperatures and/or longer cooking times favor production of Maillard reaction products.

Regression equations for beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver, and umami accounted for 36, 32, 32, 31, 31, 24, and 60 (P <0.15) percent of the variability, respectively using volatile aromatic compounds as the independent variables. Overall, grill and beef flavor accounted for 90 percent of the variation in overall consumer liking. Through interviews, consumers indicated that flavor was extremely important to them when eating beef.

DEDICATION

This work is dedicated to my family, friends, and colleagues who have helped develop me into the person I am today. Without their unwavering support and guidance, none of this work would have been possible.

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CHAPTER I

INTRODUCTION

The beef industry is always striving to understand and manage the desires of the consumer in order to create more consistent and satisfying eating experiences. Beef flavor is the driving factor in consumer acceptability. Supporting studies show that consumers rate flavor as the most important attribute for beef palatability (Miller et al., 1995; Huffman et al., 1996; Reicks et al., 2011), and 67 percent of the variation in overall beef palatability from consumer in-home studies can be attributed to flavor (Huffman et al., 1996). With that, defining and managing this vital factor that greatly contributes to consumers' overall eating experience is complex and challenging.

The beef industry took the first big step in addressing beef flavor by funding the development of the beef flavor lexicon (Adhikari et al., 2011), which identified major and minor beef flavor components. Miller and Kerth (2012) continued this research by determining that multiple chemical compounds contribute to each flavor descriptor and then comprised data that can be used to more closely identify key aromatic, volatile flavor compounds to be used as indicator compounds in future studies. Kerth (2013) investigated various levels of Maillard reaction products on beef steaks and the impact on flavor chemistry. This research showed that varying levels of steak thickness cooked with differing cook surface temperatures to a consistent degree of doneness created a variety of aromatic volatiles that are characteristic of multiple aroma descriptors. The chemical results of this research were then characterized into products likely derived

from the primary flavor classifications: likely Maillard reaction product (LMRP), likely lipid degradation product (LLDP), the ratio of likely lipid degradation product to likely Maillard reaction product (LLDP:LMRP), sulfur-containing compounds, nitrogen-containing compounds, aldehydes, alcohols, ketones, acids, alkanes, alkenes, furans, pyrazines, benzenes, ring structures and straight compounds.

The objectives of this project were to create varying levels of positive and negative beef flavor attributes by selecting different beef cuts that varied in quality grade, pH, and amount of connective tissue, and then prepare these steaks and roasts utilizing three different methods of cooking to manipulate the extent of browning and degree of doneness. Steaks and roasts were tested for specific flavor differences utilizing a trained descriptive panel, and then tested for flavor liking and disliking by consumers representing four cities. Once this data was obtained, gas chromatography with olfactory ports (GC-O) technology was utilized to measure the aromatic and volatile chemical compounds created by the aforementioned variables. Finally, fatty acid composition, non-heme iron content, myoglobin content, pH, and fat and moisture analysis were determined to correlate chemical properties of the raw steak to flavor profiles of the cooked steak. Doing so allowed us to correlate consumer positive and negative flavor attributes with the trained panel beef lexicon and chemicals that contribute to beef flavor. The main objective was to understand factors, whether they were chemical, volatile, or trained flavor descriptive attributes that drive consumer liking in moderate to heavy beef eaters.

CHAPTER II

LITERATURE REVIEW

Biological Response to Flavor

As defined by Meilgaard et al. (2007), flavor is the sum of perceptions resulting from stimulation of the sense ends that are grouped together at the entrance of the alimentary and respiratory tracts. When conducting practical sensory analyses, flavor is restricted to the impressions perceived via the chemical senses from a product, including: aromatics, tastes or gustatory perceptions (sweet, sour, salty, bitter) caused by water-soluble compounds in the mouth, and the chemical-feeling factors that stimulate nerve ends in the soft membranes of the buccal and nasal cavities (Meilgaard et al., 2007). It is important to note that flavor does not include appearance or texture.

Aromatics are the volatiles perceived by the olfactory system from a substance in the mouth via posterior nares. Once the aromatics interact with the olfactory receptor neurons, the axons arising from the receptor cells project directly to neurons in the olfactory bulb, which in turn, projects to the pyriform cortex in the temporal lobe of the brain. What makes the olfactory system unique is that among the sensory systems, it does not entail a thalamic delay en route to process the information. Further processing in the various regions of the brain allows the aroma to be identified and initiates responses to the olfactory stimuli, thus characterizing a "smell" (Meilgaard et al., 2007). When evaluating the aromatics of a product or during research, there is the opportunity

for contact with the volatile being too brief, not allowing a panelist time to accurately characterize and describe the aromatic event.

The temperature and the product's nature affect the amount of volatiles that escapes from a product. The vapor pressure of a substance exponentially increases with temperature. The odorous molecules must be transmitted by a gas (the atmosphere, water vapor, or an industrial gas) and the intensity of the perceived odor is determined by the proportion of gas that comes into contact with the observer's olfactory receptors (Laing, 1983). Each olfactory receptor is unique and has different sensitivities, as illustrated by the varying levels of sensitivity to floral and sulfuric compounds. Humans are able to detect very low levels of sulfur compounds, whereas higher levels of some floral compounds are needed for humans to detect the same level of intensity.

Gustation involves the detection of stimuli dissolved in water, oil, or saliva by the taste buds that are primarily located on the surface of the tongue as well as in the mucosa of the palate and areas of the throat (Meilgaard et al., 2007). Unlike with olfaction where there is a risk of contact with a solution being too brief, gustation provides the opportunity for a more consistent contact between a solution and the taste epithelium on the tongue and walls of the mouth (Meilgaard et al., 2007). Oversaturation of the taste receptors can occur and lead to persistent after-taste. The gustatory senses are bathed in saliva, a complex solution containing water, amino acids, proteins, sugars, organic acids, and salts, and they are fed and maintained by blood, which contains an even more complex mixture of the same substances.

Beef Flavor

Beef flavor is not a single attribute, but rather multiple attributes and, as a result, is an incredibly complex topic. Entire books have been written on the study of meat flavor. Beef flavor is a result of the combination of substances present in the raw beef steak, as well as those created by chemical reactions occurring during the heating process. The initial investigation of beef flavor began when Hornstein et al. (1960) demonstrated that as hamburgers were prepared from water-extracted ground beef, they were essentially tasteless and odorless. On the other hand, the water extract developed a beef aroma when concentrated and heated; thus, discovering the main flavor contributors were water-soluble. Additionally, they determined that an oily, viscous, liquid solution with a low vapor pressure also emitted a strong aroma. The need to build on decades of work and gain further understanding of beef flavor is important to the beef industry. Recent advancements include the standardized beef flavor lexicon, and technological advancements, such as the addition of the olfactory ports to the gas chromatography (GC) and mass spectrometry (MS) system.

Flavor research to understand what chemical compounds comprise positive and negative beef flavors is an ongoing process. Miller and Kerth (2012) identified positive and negative beef flavors from the beef lexicon (Adhikari et al., 2011). The positive beef flavors identified in the beef lexicon are beefy, brown/roasted, bloody/serumy, fat-like, sweet, salty, and umami (Miller and Kerth, 2012). Attributes that are generally considered negative are metallic, liver-like, sour, barnyard, musty-earthy/humus and bitter. Beefy, browned/roasted, bloody/serumy, sweet, salty and umami are associated

with the lean portion of beef; while, fat-like, liver-like, metallic and bitter are associated with the lipid portion (Miller and Kerth, 2012). Beef with a higher pH, oxidized beef fat, and high concentrations of myoglobin content can cause liver-like, metallic and other off-flavors. Roasts tend to have slightly higher levels of barnyard and musty-earthy/humus, and when these flavors are combined with beefy, brown/roasted and umami attributes, may develop into flavors consumers perceive as positive (Miller and Kerth, 2012).

Beef Flavor Development

Meat is comprised of water, proteins, lipids, carbohydrates, minerals, and vitamins. Proteins, lipids and carbohydrates play primary roles in flavor development, because they include numerous compounds that are capable of developing into important flavor precursors when heated. These flavors include roasted, fatty, boiled, species-specific aromas, as well as the characteristic meaty aromas (Mottram, 1998). Mottram (1998) divided flavor precursors into two major categories: water-soluble components and lipids. Flavor precursors can be described as volatile or non-volatile. Volatile compounds are both aromatic and non-aromatic, react with other compounds, and most importantly contribute to flavor. Non-volatile compounds do not directly contribute to flavor. An aroma compound is volatile and can be sensed by the olfactory system. An aromatic compound is one of a large class of unsaturated chemical compounds characterized by one or more planar rings of atoms joined by covalent bonds of two different kinds.

The water-soluble components of beef flavor include: amino acids, carbohydrates, nucleotides, peptides, and nitrogenous compounds, such as thiamine. The two main precursors to the water-soluble aromatic flavor components are cysteine and ribose. Cysteine is a sulfuric compound that, upon heating with ribose, glucose or xylose, produces a meat-like flavor (Morton et al., 1960). Wasserman and Spinelli (1972) reported that sulfuric compounds produce acceptable meat-like aromas and contribute to flavor at low concentrations. Cysteine also plays an important role in Strecker degradation, which will be addressed in the Maillard section. Ribose is one of the main sugars in muscle and is associated with the ribonucleotides, specifically adenosine triphosphate. This nucleotide is essential for muscle function and, post-slaughter, it is converted to inosine monophosphate. The thermal degradation of thiamine is involved in producing a meaty aroma in cooked meat. It is expected that thiamine-derived compounds have a greater effect on the flavor formation of pork rather than beef, because there is a higher concentration of thiamine in pork (Shahidi, 1994).

Several hundred volatile compounds derived from lipid degradation have been found in cooked meat, including: aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters, as well as aromatic compounds, especially hydrocarbons (Mottram, 1998). These compounds are a result of the oxidation of the fatty acid components of lipids and undergo reactions capable of producing rancid off-flavors during long-term storage. However, in cooked meat, the reactions occur quickly and contribute to positive flavors (Mottram, 1998). Lipid-derived volatiles are quantitatively

dominant to flavor development unless harsh cooking methods cause extensive browning, in which the effects of the Maillard reaction would reign (Mottram, 1998).

Lean muscle contains structural phospholipids and intramuscular triglycerides. Triglycerides are associated with marbling. Phospholipids are found in the cell membrane and form lipid bilayers. They are an important source of volatiles during cooking because they contain a much higher proportion of unsaturated fatty acids as compared to triglycerides. Unsaturated fatty acids undergo autoxidation much more rapidly than saturated fatty acids, leaving them more susceptible to producing undesirable oxidative and warmed-over flavors. Furthermore, phospholipids contribute positively to beef flavor through lipid oxidation during the initial stages of cooking (Mottram, 1998). Intramuscular fat, or marbling, is mainly comprised of triglycerides. Marbling's effect on beef flavor will be discussed later. Together, phospholipids and triglycerides function to make beef flavor more beefy (Mottram and Edwards, 1983).

The two primary types of lipid degradation are thermal and oxidative. Thermal degradation greatly influences the development of beef flavor, producing over half of the volatiles reported in meat flavor (Mottram, 1998). Thermal degradation occurs through the oxidation of acyl chains (Mottram, 1998); however, if extremely high temperatures are present, acrid or bitter flavor components may form (Wasserman and Spinelli, 1972).

Lipids and the volatiles produced during cooking greatly contribute to the odor and flavor of beef (Wood et al., 2004; Calkins and Hodgen, 2007). Adipose tissue acts as a solvent and traps the aromas that can be released during heating, therefore enhancing the intensity of the flavors present (Wasserman and Spinelli, 1972). Lipid-derived

flavors have a higher odor threshold in comparison to water-soluble components (Shaidi, 1994). This makes lipid volatiles a major precursor to the development of beef flavor (Mottram, 1998). Strong, unpleasant odors and flavors, such as painty, fishy, and heated oil are a result of lipid oxidation (Mottram, 1998; Aberle et al., 2001). Products of lipid oxidation, either from the lipid fraction or from phospholipids, have also been shown to react with Maillard reaction products. These reactions can occur during cooking or during storage. Much research has been done to prevent lipid oxidation through live animal feed ingredients and feeding methods, vacuum packaging and the addition of antioxidants to meat. Non-heme iron content has been reported to be a major catalyst in lipid oxidation, thus playing a key role in shelf-life stability (Rhee and Ziprin, 1987).

The interactions of the water- and lipid-soluble components interact to form lipid-derived aldehydes that play a vital role in the Maillard reaction and ultimately the overall aroma profiles of cooked meat. Specifically, the interaction produces multiple hetercyclic compounds with long chain alkyl substituents, such as pyrazines, thiophenes, thiazoles, and thialzolines (Shahidi, 1994).

In addition, water-soluble compounds from live animal feed ingredients deposited in lipid influence the fatty acid composition and contribute to beef flavor. A great deal of research has been conducted comparing the flavor profiles of grass-fed and grain-fed beef. The increased time an animal is forage-fed affects the total phospholipid amount and fatty acid complex, resulting in the development of the characteristic grassy flavors in grass-fed beef (Larick and Turner, 1990; Baublits et al., 2009). Perceived negative flavors associated with grass-fed beef are milky and oily (Melton et al., 1982).

Beef Species Flavor

Hornstein and Crowe (1960) discovered that beef and pork have similar meaty flavors, hypothesizing that compounds within the lean portion interacted with amino acids, carbohydrates, and polypeptides to produce the flavor of cooked meat. Simultaneously, Batzer et al. (1960) used column chromatography and gel filtration to conclude unknown, low-molecular-weight, water-soluble compounds, basic amino acids, carbohydrates, peptides, and phosphates were precursors to beef aroma. This research established that cooked meat flavor was the result of interactions between multiple compounds.

The lipid portion of the meat is what separates beef flavor from pork flavor. The different types of free fatty acids and carbonyls produce various volatiles when heated, thus emitting species-specific flavors (Hornstein and Crowe, 1960). Specifically, Mottram (1998) explained that the higher proportion of unsaturated fatty acids in the triglycerides of pork and chicken, compared with beef or lamb, gave more unsaturated volatile aldehydes in these meats and such compounds may be important in determining the specific aromas of these species.

Maillard Reaction

As discovered by Louis-Camille Maillard in 1912 (Billaud and Adrian, 2003), the Maillard reaction is a form of non-enzymatic browning that results from a chemical reaction between an amino acid and a reducing sugar, usually requiring heat. This reaction is complex and provides a number of compounds that contribute to flavor, off-flavor, aroma and odor. The primary flavors developed as a result of the Maillard

reaction are sweet and bitter flavors (Hurrell, 1982; Mottram and Whitfield, 1994). Therefore, the Maillard reaction is one of the most important components of flavor in cooked foods and has been the topic of research in many studies (Hurrell, 1982; Nursten, 1986; Tressl et al., 1993; van Boekel, 2006).

In general, amino compounds condense with a carbonyl group of a reducing sugar, producing gylcosylamine. Gylcosylamine is rearranged and dehydrated to form furfural, furanone derivatives, hydroxyketones, and dicarbonyl compounds (Nursten, 1981; Calkins and Hodgen, 2007). The classic diagram provided by (Hodge, 1953) still provides the basis for understanding non-enzymatic browning and the Maillard reaction. As the reaction progresses, the intermediates can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia through the Amadori rearrangement, Strecker degradation, and Schiff bases pathways (Nursten, 1981; Calkins and Hodgen, 2007). The positive flavors produced as a result of the Maillard reaction are: savory, meaty, roasted, and sweet. Negative flavors resulting from the Maillard reaction are bitter, metallic, and boiled. According to Calkins and Hodgen (2007), an extensive list of the nine most common aromatic compound classes from precursors of the Maillard reaction can be found in Manley and Choudhury (1999).

Strecker degradation is a reaction associated with the Maillard reaction involving the oxidative deamination and decarboxylation of an amino acid in the presence of a dicarbonyl compound. The compounds formed by Strecker degradation are important as the reactive intermediates for the formation of many highly reactive odoriferous compounds that play important roles in meat flavor, such as pyrazines and aldehydes

(Shahidi, 1994). The level of pyrazines formed is dependent on reactant conditions, such as moisture content, temperature, pH, and time (Shahidi, 1994).

Sulfur heterocyclics play a large role in the development of beef flavor. Most researchers agree that sulfur compounds are the most important volatiles formed during meat cookery (Shahidi, 1994). The most dominant sulfur compound in meat volatiles is hydrogen sulfide (Nixon et al., 1979). During cooking, large quantities of H_2S are produced and they interact with the Maillard reaction and Strecker degradation to form volatile sulfur-containing compounds. Calkins and Hodgen (2007) provided a list of compounds described as meaty. Of the 78 compounds, 65 were identified as being heterocylic sulfur compounds. Most of these compounds are furans or thiophenes. Aldehydes can react with H_2S to form dithiozines, thiols, sulphides, and trithianes (Shahidi, 1994). The Maillard reaction produces highly important chemical compounds that contribute to beef flavor, including: pyrazines, oxazoles, thiophenes, thiazoles, and other heterocyclic sulfur compounds (Shahidi, 1994).

Muscle Comparison

The majority of muscle comparison research has primarily been focused on tenderness differences, as tenderness has been shown to be up to four times more variable than beef flavor intensity (Shackelford et al., 1995). In a study conducted by Shackelford et al. (1995), the *M. Longissimus lumborum* (LM) had greater beef intensity when compared to the *M. Biceps femoris* (BF) and the BF was beefier than the *M. Gluteus medius* (GM). This data showed that the off-flavor intensity was equal in the BF

and GM. A much more in depth chart that has combined flavor research from numerous studies can be found in Calkins and Hodgen (2007).

Yancey et al. (2006) researched the effect of myoglobin concentration on the livery off-flavor in beef muscles. This research showed that the GM had a higher amount of myoglobin present in the muscle, as well as a higher incidence of the livery off-flavor. However, other research demonstrated that the full effect of myoglobin content and meat pH on flavor attributes has not been fully elucidated (Meisinger et al., 2006).

Neely et al. (1998) evaluated beef consumer perception of three different muscles, LM, GM, and *M. Adductor* (AD), that varied in quality grades. This study was an in-home use test conducted in four different cities. Consumers were able to prepare the steaks to their liking in regards to preparation method and degree of doneness. Overall, consumers preferred steaks from the LM, followed by steaks from the GM and, lastly the AD. As the AD is from the round and used for locomotion, it has been shown to be higher in connective tissue levels (Neely et al., 1998). This is why moist heat cookery is typically used to prepare steaks and roasts from the round.

Quality Grades

A marbling score is assigned to a carcass by assessing the amount of intramuscular fat in the *M. Longissimus dorsi* (LD) muscle at the 12^{th}-13^{th} rib interface, which is a primary factor in the beef quality grade formula. Consumer palatability is predicted by USDA quality grades. Research has shown that as marbling score increased from Practically Devoid to Moderately Abundant, flavor desirability increased linearly (McBee and Wiles, 1967; Smith et al., 1983). Furthermore, Smith et al. (1983)

concluded that marbling score indirectly assessed concentrations of flavor and aroma in beef. Therefore, carcasses with higher degrees of marbling should yield meat that tastes more beefy.

Smith et al. (1983) also revealed that a higher marbling score dramatically decreased the incidence of undesirable flavors. Specifically, as the marbling score increased from Practically Devoid to Moderately Abundant, the undesirable ratings decreased from more than 55 percent to zero. Applying this information to recent market research, the number of carcasses grading Ch has increased from 51 percent in 2000 to 62 percent in 2011 (Gray et al., 2012). Theoretically the incidence of undesirable flavors should decrease.

Since muscle is comprised of up to 75 percent water (Aberle et al., 2001), it is logical that moisture content decreases as fat content increases. Savell et al. (1986) performed fat and moisture analyses on steaks originating from the LD from different quality grades. The results showed that there was an inverse linear relationship between lipid and moisture percentage as lipid increased.

Fatty Acids

Neural lipids (fatty acids and glycerol) are the primary lipids found in the body (Mottram, 1998). Their purpose is to act as sources of energy for the cell, contribute to cell membrane structure and function, or be involved in metabolic activity (Spector and Yorek, 1985). In animal fats, the saturated fatty acids of palmitic acid (16:0) and stearic acid (18:0) are present in higher levels; lauric acid (12:0), myristic acid (14:0), or arachidic acid (20:4), are only present in small quantities (Wood et al., 2004).

Palmitoleic (16:1), oleic (cis 9), linoleic, (18:2, cis9) and linolenic (18:3) are the predominant unsaturated fatty acids, with 18:2, cis 9 being the most abundant fatty acid in the animal body (Wood et al., 2004).

Since lipids are organic compounds comprised of hydrogen, carbon, nitrogen, oxygen, and phosphorus, they are very soluble in organic solvents, such as, dichloromethane, chloroform, hexane, and diethyl ether. Lipids are insoluble in water solutions. When extracting lipids, the type of solution used depicts what portion of the lipid will be extracted. Phospholipids are extracted using chloroform-methanol (polar) and triglycerides are extracted using hexane. Fatty acid methyl esters (FAME) are the common extraction method developed by Morrison and Smith (1964). To prepare the FAME, fatty acids are cleaved from triglycerols, phospholipids, or any other lipid compound during methylation, to form free fatty acids. Once the free fatty acids are acetylated to a methane group, a FAME is created. The FAME is separated using gas chromatography. Lipids are then categorized by the number of carbons, or by the presence or absence of double bonds.

Baublits et al. (2009) showed a positive correlation between the positive sensory characteristics, beefy/brothy and beef fat, and fatty acids 16:0, 16:1 and eladic acid (trans 18:1), and a negative correlation with pentadecanoic acid (15:0), alpha-linoleic acid (18:3), arachidonic acid (20:4), eicosapentaenoic acid (20:5), 22:5 and docosahexaenoic acid (22:6). Results also indicated that the escalated presence of conjugated linoleic acid (CLA) and the 20- and 22-carbon polyunsaturated fatty acids increased the perceived negative attributes of grassy and dairy/oily, and decreased the

positive attribute of beef/brothy flavor. Furthermore, increased 18:1 percentages improved bloody/serumy sensory descriptor. Contrarily, an increase of heptadecanoic acid (17:0), 18:2, 20:4 and behenic acid (22:0) negatively correlated with the bloody/serumy attribute, indicating that if these fatty acids were reduced, the sensory attribute would be perceived as more positive. Additionally, the negative aromatic flavor attribute related to proteolytic storage, old/putrid, was positively correlated with 12:0, 15:0, 15:1, and a-18:3, and negatively correlated with 18:1. Finally, the sweet characteristic commonly associated with a forage flavor derived from forage rations (Larick and Turner, 1990) were negatively correlated with 20:5, 22:5 and 22:6. Overall, Baublits et al. (2009) concluded that positive beef flavor attributes were enhanced by increased percentages of saturated and monounsaturated fatty acids, while polyunsaturated fatty acids had a greater effect on the perceived negative aspects of beef flavor.

pH

High pH (pH > 6.0), or dark, firm, and dry beef (DFD), is a result of chronic long-term stress (emotional excitement, fatigue, extreme weather conditions, etc.) pre-slaughter. Long-term stress leads to the depletion of muscle glycogen, causing less lactic acid to form post harvest. Additionally, the muscle has a very dry or sticky texture due to its high water holding capacity and the more alkaline environment is a favorable medium for bacterial growth (Viljoen et al., 2002). The meat is darker red to purplish in color as a result of less total light being reflected due to the light-absorptive properties of the muscle (Aberle et al., 2001).

Because consumers tend to purchase with their eyes, dark-cutting beef has been a problem for the beef industry for many years particularly due to the less attractive dark red to purplish color and dry texture (Hedrick, 1965; Viljoen et al., 2002). Beef characterized as DFD is said to have a musty/moldy, very high beef flavor intensity, cowy/grassy, or bloody/serumy aromatic flavors (Calkins and Hodgen, 2007). Wulf (2002) researched the impact of DFD meat and cooked beef palatability. While there was no difference in flavor intensity, ratings were lower in flavor desirability for DFD steaks compared to normal. The decrease in flavor desirability is of concern to the beef industry; especially considering that the percentage of dark-cutting beef has increased in the past decade (Gray et al., 2012).

Mottram and Edwards (1983) studied the effect of pH on the formation of volatile compounds in meat-related model systems and determined that the color, overall aroma and the nature of the volatile compounds were influenced by pH. From a flavor chemistry perspective, nitrogen-containing compounds were detected at higher pH levels and as the pH increased, 3-(methylthio) propanal and disulfide increased in concentration and amount, respectively.

Degree of Doneness

Raw meat has been described as weak, salty, and blood-like and the desirable characteristic beefy flavors evolved as the degree of doneness increased (Crocker, 1948). The temperature of the heating element and the method of cooking affect the rate of cooking (Crocker, 1948). This, combined with the final degree of doneness, impacted the rate and extent of chemical reactions (Kerth, 2013). Hence, cooking method and final

temperature greatly affect what flavor volatiles may develop from the flavor compounds that are present in raw beef (Miller and Kerth, 2012). Calkins and Hodgen (2007) discussed that varying cooking methods and internal temperatures yielded different flavors ranging from relatively bland to strong meaty notes, some with a high grill-like flavor, and others were distinctly roasted. Bowers et al. (1987) cooked strip steaks to seven different endpoint cooking temperatures ranging from 58 °C to 80 °C. This research determined that the various endpoint temperatures influenced panel ratings for flavors and juiciness. As endpoint temperatures increased, mouth-filling flavor blend and browned flavor increased, while bloody/serumy, metallic and sourness decreased. As expected, juiciness declined linearly as the final temperature increased.

Belk et al. (1993) cooked beef roasts to four different internal temperatures to evaluate flavor differences. At lower temperatures, metallic and astringent mouth feel and bitter, sour, bloody/serumy, painty, and soured aromatics were more highly detected. As the temperature increased, so did cooked beefy/brothy, cowy/grainy, cardboardy and livery flavors.

Consumer Acceptance

Consumer preference is a combination of deliberate, conscious decisions and choices that are influenced by factors unaware to the individual (Fitzsimons et al., 2002). A variety of cognitive, contextual, and environmental or learned behaviors can influence the perception and interpretation of sensory information (Lee et al., 2006; Shankar et al., 2009). Furthermore, research has documented that color or visual appearance effects consumer's perception of flavor (Sakai et al., 2005; Levitan et al., 2008). These factors

play a role in segregating multiple consumer segments that have different preferences for degree of doneness, muscle, flavor attributes or recipe flavor classes, and cooking methods.

Past market research identified in Neely et al. (1998) discussed the differing consumer preferences across the United States. Consumers from around the country tend to have varying preferences in terms of fat trim and quality grade. This drives the type of beef sold at retail markets. The aforementioned studies found that USDA Choice (Ch) beef is featured in the northeast, so consumers from Philadelphia favored beef with greater marbling. On the other hand, San Francisco offered beef from lower grades, thus consumers placed lower emphasis on marbling content. Research from Neely et al. (1998) supported the previously documented studies in that consumers in the traditionally USDA Ch markets showed much greater preference for Top Ch (upper two-thirds of USDA Ch) steaks. However, consumers in traditionally USDA Select (Se) markets were not always able to distinguish between quality grades. Because beef is so complex and consumers across the nation have broad preferences, it is challenging to strongly correlate consumer acceptance with the volatile compounds and flavor components of beef.

GC and MS

The GC and MS systems have undoubtedly been the technique of choice for all instrumental flavor and aroma analysis for nearly four decades (Shahidi, 1994). The GC reigns as the optimal method of separating volatile flavors and aromas into compounds, while the MS is the most powerful technique to identify unknown compounds (Shahidi,

1994). This technique is widely accepted and routine in flavor studies of muscle foods; however, an explanation of the process is provided in Shahidi (1994).

The GC and MS technologies are capable of detecting hundreds of volatile compounds within one sample, however not all of the compounds collected are aromatic. The addition of the gas chromatography with olfactory ports (GC-O) allows for the identification of aroma-active components. In GC-O, the volatiles are separated by the GC column then transported to the olfactory meter, where they are combined with humidified air (Shahidi, 1994) to prevent human nasal passages from drying out. To test the sample, a trained panelist sniffs aromas as they exit the machine through the olfactory port. The aroma and intensity of the aroma is identified and quantified by the panelist and recorded through selected software programs.

An increase in the popularity of flavor research has been spurred by advancements in GC-O technology. There are indications that only small fractions of a large number of volatiles occurring in food actually contribute to odor and aroma (Mottram, 1998). One aspect of the GC-O technology is that individual compounds have different odor thresholds, or the human detects them at different concentrations (Shahidi, 1994). Therefore, odors can occur at very low concentration and have sensory relevance due to low odor threshold values. Thus, the peak profile obtained by any chemical detector does not necessarily reflect the human identified aroma profile of a compound.

Some challenges associated with operating the GC-O machine involve human error and delayed response time with the trained panelist. Panelists also run the risk for contact with the aromatic compounds simply being too brief for the mind to interpret and

characterize. Nonetheless, GC-O technology is instrumental in identifying flavor compounds and aroma profiles in food products. The data collected has been correlated to trained sensory panel flavor ratings and consumer liking (Calkins and Hodgen, 2007; Larick et al., 1987; Yancey et al., 2006).

CHAPTER III

MATERIALS AND METHODS

Sample Selection and Preparation

Beef subprimals (Ch LM, high pH [>6.0] LM), Ch GM, Se BF, and Ch BF) were obtained from 10 beef carcasses (2 per carcass) on one selection day at Sam Kane Beef Processors in Corpus Christi, TX. These steaks and roasts were selected to differ in flavor based on previous research (Miller and Kerth, 2012). Subprimals were cut into steaks (Ch LM, Ch GM, high pH LM; 2.54 cm thick with 0.25 cm external fat) or roasts (Se and Ch BF; 1.3 kg). Steaks and roasts were vacuum-packaged, frozen and stored at -40 °C until evaluated. Steaks and roasts were cooked to 58 or 80 °C internal temperature to induce differences in degree of doneness, bloody/serumy, liver-like, beefy, and brown/roasted flavor aromatics, and Maillard reaction products. These degrees of doneness and quality grade/cut differences also were used to affect the level of umami, fat-like, and metallic flavor attributes. To further induce differences in beef flavor attributes, steaks were cooked using different cooking methods to induce differences in Maillard reaction products and heat-induced lipid oxidation. Steaks were cooked either on a George Foreman Precision Grill-Model GRP99 (GF; George Foreman/Applica Consumer Products Inc., Miramar, FL) set at 190 °C or a serrated gas or flat top grill at 232 °C. Roasts were cooked in a Crock-Pot Manual Slow Cooker (CP; Jarden Corporation, Inc. Boca Raton, FL), oval 5.67 liters on the high setting. Internal temperatures were monitored by iron-constantan thermocouples (Omega Engineering,

Stanford, CT) inserted into the steak or roast geometric center. Temperatures were displayed using an Omega HH501BT Type T thermometer.

This design resulted in 16 flavor treatments within a carcass. Each treatment within a cut and carcass were prepared for expert, trained descriptive attribute flavor evaluation; consumer sensory evaluation in Philadelphia PA, Houston TX, Portland OR, and Olathe, KS; cooked chemical flavor volatile analysis; raw chemical fat/moisture, pH, non-heme iron, myoglobin, and fatty acid analyses.

Expert, Trained Descriptive Beef Flavor Analysis

Steaks and roasts were evaluated by an expert trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon. This panel was retrained using the beef lexicon for 14 d. Beef flavor attributes were measured using the Beef Lexicon (0 = none and 15 = extremely intense) defined in Table 1. After training was complete, panelists were presented 12 samples per day. Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm up" sample that was evaluated and discussed orally. After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each beef flavor lexicon attribute. Double distilled water, unsalted saltine crackers and ricotta cheese were available for cleansing the palette between samples. During evaluation, panelists were seated in individual breadbox style booths separated from the preparation area and samples were evaluated under red-light. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions and samples were served four minutes apart.

After cooking, samples were cut into 1.27 cm cubes. Two cubes per sample were served in clear, plastic soufflé cups tested to assure that they did not impart flavors on the samples. Samples were identified with random three-digit codes and served in random order. Samples were cut and served immediately to assure samples were approximately 60 °C upon time of serving (AMSA, 1995).

Consumer Evaluation

Consumers (n = 80 per city) were randomly selected in four cities (Houston, TX; Olathe, KS; Philadelphia, PN; and Portland, OR) so that geographical areas were representing the South, the Midwest, the east coast and the west coast. In each city, four consumer sessions with approximately 20 consumers per session were conducted. After completion of each consumer session, five consumers (n = 20 consumers per city) were asked to participate in one-on-one interviews to determine attitudes toward beef and beef flavor.

Consumer panelists were recruited by the individual research intuition and all panelists were required to pass a consumer screener guaranteeing them to be over 18 years of age, have no food allergies, and consume beef three or more times per week. On the day of evaluation, recruited consumer panelists were asked to sign an informed consent document. An instructional document, demographic ballot and eight individual sample ballots were provided to the consumer upon entering the testing room. Consumer demographics for age, sex, income, household income, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, and meat shopping habits were determined. The ballot included overall liking, overall flavor

liking, beefy flavor liking and intensity, grilled flavor liking and intensity, and off flavor intensity rankings using a nine-point hedonic or intensity scales. Open-ended questions to list any additional positive flavors and negative flavors were presented after the scales. Panelists were provided eight pre-identified random samples in a pre-determined random order four minutes apart. Samples were served in clear plastic weigh boat containers labeled with a random three-digit number corresponding to their ballot. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis.

Cooked Beef Volatile Flavor Evaluation

Volatiles were captured from the same steaks or roasts evaluated by the consumer panelists in Olathe, KS. After samples were prepared for consumers, approximately 75 g of 1.27 cm beef cubes were placed in foil with a tag separated from the meat samples. Samples were placed in liquid nitrogen and frozen to -196 °C. Samples were stored at -80 °C until volatile analysis. Volatiles were evaluated using the AromaTrax and GC-O for characterization of aromatics. This technology provided the opportunity to separate individual volatile compounds, identify their chemical structure and characterize the aroma/flavor associated with the compound at parts per trillion. Samples were partially thawed and placed in heated glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas and then set in a water bath at 60 °C where the headspace was collected with a Solid-Phase Micro-Extraction (SPME) Portable Field Sampler (Supelco 504831, 75 μm Carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, Mo). Headspace above each meat sample in the glass jar was

collected for 2 h for each sample after the sample reached 60 °C. Upon completion of collection, the SPME was injected in the injection port of the GC, where the sample was desorbed at 280 °C. The sample was then loaded onto the multi-dimensional GC into the first column (30m X 0.53mm ID/ BPX5 (5% Phenyl Polysilphenylene-siloxane) X 0.5 µm, SGE Analytical Sciences, Austin, TX), which separates compounds based on boiling point. Through the first column, the temperature started at 40 °C and increased at a rate of 7 °C per minute until reaching 220 °C. Upon passing through the first column, the compounds passed to the second column {(30m X 0.53mm ID)(BP20- Polyethylene Glycol) X 0.50 µm, SGE Analytical Sciences, Austin, TX}, which separates compounds due to polarity. The GC column was then partitioned into three different columns at a three-way valve with one going to the MS (Agilient Technologies 5975 Series MSD, Santa Clara, CA) and two going to the two humidified sniff ports, which were heated to a temperature of 115 °C, with glass nose pieces. The sniff ports and software for determining flavor and aroma are a part of the AromaTrax program (Micro Analytics-AromaTrax, Round Rock, TX). Panelists were trained to accurately use the AromaTrax software, after they had also been trained according to the Beef Lexicon aromas.

Raw Chemical Analyses

Raw meat pH, fatty acid composition, myoglobin content, and non-heme iron content were determined from each raw muscle (Ch LM, Ch GM, high pH LM, Ch BF, and Se BF) within a carcass. The pH was determined in duplicate (pH meter calibrated daily with 4.0 and 7.0 pH buffer solutions; IQ Scientific Instrument, Model IQ150, IQ

Scientific Instrument, Inc., Carlsbad, CA, U.S.A.) by inserting the probe in two random locations within the anterior face of each subprimal.

Fatty acid methyl esters were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately three to five g of ground beef was combined with 1 mL of 0.5 M KOH in MeOH and heated at 70 °C for 10 min. After cooling, 1 mL of Boron trifluoride (BF3 (14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70 °C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC grade hexane and 2 mL of saturated NaCl were added to the samples and vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. The sample was evaporated to dryness at 60 °C under N_2 gas, subsequently reconstituted with HPLC grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 auto- sampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 [100 m x 0.25 mm (i.d.)] (Chrompack Inc., Middleburg, The Netherlands), with He as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180 °C, oven temperature increased at 20 °C/min to 225 °C and held for 13.75 min. Total run time was 48 min. Injector and detector temperatures were at 270 °C and 300 °C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for

identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

Myoglobin concentration was conducted according to Rickansrud and Henrickson (1967) with modification to be read using a 96 - well plate reader. Duplicate 25 g samples were blended with 100 mL of DDH_20 for 3 min and centrifuged at 2,000 x *g* at six °C for 15 min. The supernatant was filtered through Whatman No. 3 filter paper and brought to volume in a 200 mL volumetric flask. From this 200 mL portion, duplicate 5 mL portions were taken and adjusted to pH of 7.1 using 0.5 M phosphate buffer. Then, 1.25 mL of saturated lead acetate was added to the tube and centrifuged at 2,000 x *g* for 15 min. Finally, 2.5 mL of the supernatant was combined with a mixture of mono- and dibasic phosphate to bring the phosphate concentration to 3 M and the pH to 6.6 and was again centrifuged at 2,000 x *g* for 15 min. One milliliter of the supernatant was combined with 0.7 mL of potassium ferricyanie and 0.7 mL of potassium cyanide to convert all forms of myoglobin to cyanmetmyoglobin. The samples were again centrifuged at 2,000 x *g* for 15 min to ensure that all myoglobin had been transformed, and 200 μL were pipetted in triplicate on a 96 - well plate and read at 520 nm.

For non-heme iron, samples were prepared following the procedures described by Rhee and Ziprin (1987) and read at 540 nm using a Cary 100 Varian UV/Visual Spectrophotometer (Varian Instruments, Sugarland, TX). To determine total non-heme iron, final absorbance of each sample was calculated by subtracting the absorbance of the incubated liquid phase with no color reagent added from the absorbance of the

incubated liquid phase with color reagent added. Next, final concentration was calculated by subtracting the intercept of the standard curve from the final absorbance and dividing by the slope of the standard curve. Non-heme iron content was calculated as follows: *u*g non-heme Fe/g meat = concentration (*u*g/mL) x (15 + 0.2 + moisture in 5g of meat) 5g x 1mL.

Statistical Analyses

The trained panel descriptive flavor attributes and the volatile compounds were analyzed using Proc Means, Proc Corr, Proc Reg stepwise procedure, and Proc GLM of SAS (version 9.3, SAS Institute, Cary, NC) to understand what chemical attributes drive specific beef flavor attributes. A predetermined alpha of ($P < 0.05$) was used in all analyses. For stepwise regression analysis, dependent variables were defined as overall consumer liking and trained descriptive attributes of beef identity, brown/roasted, bloody/serumy, metallic, liver-like and umami. Independent variables were volatile compounds defined using the Aroma Trax and were allowed to enter the equation ($P \leq 0.05$). Final equations were presented and the intercept ß values and partial r^2 for each independent variable and final equation for r^2 are presented. For Analysis of Variance of chemical data, treatment was defines as a completely random design. For trained panel data, data were averaged across panelists and sensory day and order served were defined as random variables. For consumer data, city, treatment and their interaction were included as main effects and order served was defined as a random variable. For volatile category data, treatment was included as the main effect. Least squares means were

calculated and the pdiff function of SAS was used to determine differences between means when significance was defined in analysis of variance table.

Principal component analysis was conducted using XLSTAT (v2013, Microsoft Corporation, Redmond, WA). Data were averaged across treatments and Pearson correlations were used to remove cross correlations within the data. Principal components one and two were presented in bi-plots.

CHAPTER IV

RESULTS AND DISCUSSION

Trained Panel Flavor Attributes

As outlined by the beef lexicon, the definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes used in this study, as well as their intensities are listed in Table 1 (Adhikari et al., 2011). The flavor level (intensity) is presented in a numerical value ranging from 0 to 15, where 0 is described as not detectable and 15 is extremely intense.

Beef identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like and umami differed ($P < 0.05$) across treatments (Table 2). Cooking method, cut, and internal temperature impacted the beef flavor attributes ($P < 0.05$) referenced in Table 2. Beef flavor attributes that were evaluated, but not present in any samples were green hay-like, barnyard, rancid, heated oil, blue cheese, chemical, cumin, warmed over flavor, refrigerator stale, butter, soapy, sour milk dairy, chocolate, spoiled, dairy, medicinal, smoky wood, petroleum, painty and fishy aromatics. As flavor levels for these attributes were zero, data were not presented.

Treatments affected beef flavor attributes as intended. As degree of doneness increased, beef identity increased ($P < 0.05$). Beef identity was higher in Ch GM steaks, Ch and Se BF roasts, and grilled high pH LM steaks cooked to 80 °C than the companion steaks cooked to 58 °C ($P < 0.05$). High pH LM steaks had less beef identity than Ch LM steaks when cooked on the GF grill to either internal temperature endpoint

or cooked on the grill to 58 °C internal temperature ($P < 0.05$). Ch BF roasts cooked to 58 °C had a higher beef identity compared to the Se BF roast cooked in the CP to 58 °C ($P < 0.05$).

Brown/roasted was lower and bloody/serumy was higher when steaks or roasts were cooked to lower internal temperature endpoints ($P < 0.05$). Fat-like flavor differed slightly across treatments and metallic was slightly higher in steaks and roasts cooked to higher degrees of doneness ($P < 0.05$). Liver-like flavor was slightly detectable in Ch BF roasts and Se BF roasts cooked to 80 °C.

Umami increased in Ch GM and LM steaks cooked from 58 to 80 °C, regardless of cooking method ($P < 0.05$). In Ch and Se BF roasts, as internal temperature endpoint increased, umami slightly increased ($P < 0.05$). Umami did not differ in high pH LM steaks across cooking methods and internal cook temperature endpoint.

Sour and bitter basic tastes were lower when Ch and Se BF roasts were cooked to the higher internal temperature endpoint ($P < 0.05$). Overall sweet, cardboardy, and sour dairy differed in intensity across treatments ($P < 0.05$), but differences were slight. Warmed over flavor did not differ across treatments ($P = 0.25$).

These results showed that cooking method, muscle, and internal temperature endpoint impacted beef flavor attributes as defined by the beef flavor lexicon. These results were expected and compatible with the trained descriptive panel results from a recent beef flavor study conducted by Miller and Kerth (2012); however, their research did not determine if these differences could be detected by consumers.

Consumer Demographics

The demographics of the consumers (n = 301) selected to participate in this study is reported in Table 3. Slightly more females participated than males. The age ranged from under 20 (but over 18), to over 66, however nearly 50 percent of consumers were between ages 21 and 35. The income of consumers spanned a broad range with 21.93 percent of consumers earning below $20,000 per year and 20.27 percent earning greater than $100,000 per year. The vast majority of the selected population consumed chicken, beef, pork, fish, lamb, eggs and soy. As expected, the majority of consumers consumed beef three or more times per week, and 20 consumers said that they ate beef every day. Purchasing habits were determined and the majority of consumers did not purchase grass-fed, dry-aged, or organic beef. The primary classification of beef bought by consumers in this study was traditional.

Consumer Perception of Beef Flavors

Table 4 shows consumer perceptions of steaks and roasts by treatment. Overall, consumers liked Ch LM steaks cooked on the grill to lower internal temperature endpoints ($P < 0.05$) the most, followed by Ch GM steaks cooked on the grill to 58 °C, Ch LM steaks cooked on the grill to 80 °C, and High pH LM steaks cooked on the grill to 80 °C. Consumers had the lowest preference for Se BF roasts cooked in the CP to 80 °C ($P < 0.05$). These results agreed with a nationwide, in-home beef palatability consumer study comparing steaks from the GM, LM, and BF. Neely et al. (1998) reported that regardless of quality grade or degree of doneness, steaks originating from the BF were the least preferred ($P < 0.05$). For high-pH LM steaks, consumers liked

grilled steaks cooked to 80 °C more than these steaks cooked to lower degrees of doneness or prepared on the GF ($P < 0.05$).

Consumers liked the grilled flavor present in beef, which should be expected as past research has shown that consumers tend to prepare steaks on an outdoor grill more often than indoor cooking methods (Savell et al., 1999). Overall liking ratings were higher for the Ch GM cooked to 58 °C on the grill compared to the GF ($P < 0.05$). All steaks prepared on the grill, regardless of muscle, ranked higher for overall liking as compared to roasts prepared in the CP, regardless of internal temperature or QG. The Ch LM steaks cooked on a grill were preferred to steaks cooked on the GF ($P < 0.05$). High pH LM steaks cooked to a high degree of doneness on the grill were preferred over high pH steaks prepared on the GF ($P < 0.05$).

Flavor liking and beef flavor liking showed similar results to overall liking ratings across treatments. Beef flavor intensity, grill flavor liking, and grill flavor intensity were higher for Ch LM steaks cooked using a grill compared to steaks cooked on the GF ($P < 0.05$). High-pH LM steaks grilled and cooked to 80 °C were rated higher for beef flavor intensity, grill flavor liking, and grill flavor intensity ($P < 0.05$). Choice GM steaks cooked on the grill ranked higher for grill flavor liking and intensity as compared to Ch GM steaks prepared on the GF ($P < 0.05$). These results agreed with Savell et al. (1999) who also found higher flavor intensity ratings when steaks were cooked on an outside grill. As expected, all steaks cooked on the grill received higher ratings for grill flavor liking and intensity as compared to Ch and Se BF roasts cooked in the CP ($P < 0.05$). Off-flavor intensity was highest in grilled Ch LM steaks cooked to

80 °C and lowest in Se BF roasts cooked in the CP to 80 °C ($P < 0.05$). Off-flavor occurrences may have been due to the bitter and metallic flavors that can develop as a result of intense surface browning. These results indicated that consumers can assess differences in beef flavor attributes and that differences in flavor impacted overall liking.

Trained Descriptive Flavor Panel and Consumer Perception of Beef Interaction

The relationship between trained descriptive beef flavor attributes and consumer acceptance is reported in Table 5. This table showed that descriptive beef flavor attributes of fat-like and brown/roasted were moderately related to overall consumer liking. Therefore, as brown/roasted and fat-like increased, consumer liking scores increased or consumers liked the beef more ($P < 0.05$). Bloody/serumy, liver-like, and salty were also slightly and positively related to consumer overall liking ($P < 0.05$). Slight relationships between beef flavor descriptive attributes of brown/roasted, bloody/serumy, fat-like, metallic, liver-like, sour and salty correlated with flavor liking and beef flavor liking. As a result, as brown/roasted and fat-like increased, consumers liked the flavor and beef flavor more ($P < 0.05$). Beef flavor intensity was slightly related to brown/roasted, bloody/serumy, fat-like, sour, and salty. Brown/roasted and fat-like beef flavor attributes were moderately and positively related to grill flavor liking and intensity ($P < 0.05$). As brown/roasted and fat-like beef flavor attributes increased, consumers liked the grill flavor more and steaks and roasts had more grilled flavor intensity ($P < 0.05$). This research agreed with Lorenzen et al (1999). Consumers expressed a greater preference for steaks containing a higher intramuscular fat content, and in turn a higher fat flavor. Off-flavor intensity was moderately related to

brown/roasted and fat-like flavor attributes ($P < 0.05$). Off-flavor in beef has been highly related to lipid oxidation and heat denaturation. Beef with a higher fat level, or higher fat-like flavor, have been shown to develop more lipid oxidation products during cooking (Shahidi, 1994). Steaks and roasts with higher levels of brown/roasted were cooked to higher internal temperature endpoints (Table 2). Cooking longer to obtain higher internal temperature endpoints also would result in more off-flavors associated with lipid oxidation and heat denaturation (Mottram, 1998).

To understand how consumer attributes influenced overall consumer liking, the linear regression equation including only consumer variables to predict overall consumer liking is reported in Table 6. Overall flavor, grill flavor and beef flavor accounted for 90 percent of the variation in overall consumer liking. This indicated that overall flavor, grilled flavor and beef flavor drove overall consumer liking. In a survey conducted by Reicks et al. (2011) that assessed how demographics and beef preferences affected consumer motivation for purchasing fresh beef steaks and roasts, similar results were found. Flavor was the top-ranked purchase motivator among all consumer segments.

To further assess the relationship between trained panel descriptors and consumer liking, principal component analysis was conducted (Figure 1). Trained panel descriptors of beef flavor, fat-like, brown/roasted, and consumer attributes of overall flavor liking, beef flavor liking, grilled flavor liking and off-flavor intensity were related to overall consumer liking (Figure 1). Metallic and bloody/serumy clustered together and were opposite of umami and beef identity. These results indicated that as umami, brown/roasted and beef identity increased, metallic and bloody/serumy decreased. Liver-

like segmented opposite of overall liking, fat-like and brown/roasted. These results reinforced findings from Table 5, indicating that browned/roasted and fat-like, and grilled flavor and overall flavor drove overall consumer liking and liver-like flavor was not associated with consumer overall liking. Cooking treatments influenced the flavors present. Fat-like closely clustered with the Ch LM steaks cooked on the grill to 58 °C. The high pH steaks cooked on a grill and the Ch LM steaks cooked on a grill to a high degree of doneness clustered with salty and butter. The aforementioned clusters were most closely related to the consumer attributes. Opposite of overall liking, the Ch and Se BF roasts cooked in a CP to 80 °C clustered together and segmented with warmed-over flavor, cardboard and liver-like. Choice GM steaks cooked on the GF and grill to 58 °C closely clustered with medicinal and sour milk. The high pH steaks cooked to the grill and GF to a low degree of doneness clustered with musty.

Raw Chemical Attributes

Chemical attributes were determined on raw steaks and roasts prior to cooking (Tables 7 and 8). As expected, pH was highest for LM steaks for carcasses that were selected for a pH of over 6.0 ($P < 0.05$). Non-heme iron was highest in Ch GM steaks and Se BF roasts ($P < 0.05$). Myoglobin content was higher in Ch LM than Ch and Se BF roasts, and Ch GM steaks. Select BF roasts had less myoglobin concentration than Ch GM and high pH steaks ($P < 0.05$). Moisture percentages did not differ across treatments ($P > 0.05$). Lipid content was lower in Ch GM steaks than Ch BF roasts and Ch LM steaks ($P < 0.05$). The fatty acids that differed ($P < 0.05$) across muscles were 14:1, 16:1, 18:0, 18:1 cis 9, 18:2, and the total trans fatty acids (Table 8). Select and Ch

BF roasts had a greater amount of 14:1 fatty acids as compared to Ch GM steaks. Choice GM steaks had the lowest concentrations of 16:1. Roasts of both quality grades had lower amounts of 18:0 than high pH and Ch GM steaks. Fatty acid 18:1 cis 9 was highest in Ch BF roasts and lowest in Ch GM steaks. Select BF roasts and Ch GM steaks had higher ($P < 0.05$) concentrations of 18:2 than Ch LM and high pH LM steaks. The total trans fatty acids were higher in Ch LM, high pH, and GM steaks as compared to Ch BF roasts. Previous literature has linked raw chemical data and fatty acid content to beef flavor (Wood et al., 2004; Meisinger et al., 2006; Yancey et al., 2006; Calkins and Hodgen, 2007).

Table 9 showed the correlation coefficients between fatty acid composition and trained descriptive sensory panel flavor attributes. Beef flavor was slightly negatively correlated with 18:1 cis 11 and 22:6 ($P < 0.05$). Brown/roasted was slightly correlated ($P < 0.05$) with fatty acid 17:0. No fatty acid had a significant ($P > 0.05$) relationship to bloody/serumy. Fatty acids 15:0, 18:0, and 20:5 were positively related to fat-like, while 18:2, 20:4, and 24:0 were negatively related to fat-like flavor ($P < 0.05$). Fatty acids 18:2 and 20:4 were positively correlated with metallic whereas, fatty acids15:0, 16:1, 17:1, and 18:1 cis 9 were negatively correlated with metallic ($P < 0.05$). It is interesting to note that the majority of the shorter fatty acid chains had a positive relationship with overall sweet, while the longer fatty acid chains had the opposite effect ($P < 0.05$). Fatty acids 15:0, 16:1, 17:1, and cis 9 had a moderate, positive correlation with sweet, whereas 18:2 and 20:4 were negatively related ($P < 0.05$).

The relationship between fatty acid composition and consumer sensory attributes was displayed in Table 10. Interestingly, fatty acids 22:6 and Total trans were not strongly related to trained panel attributes, but were correlated ($r > 0.15$; $P < 0.05$) with all consumer sensory attributes. Fatty acids 16:0 and 18:0 positively related to consumer overall liking and 18:2 and 20:4 negatively correlated with overall liking ($P < 0.05$). Flavor liking was negatively correlated to 20:4. Grill flavor liking was positively correlated with 18:0 and negatively correlated to 20:4 ($P < 0.05$). Furthermore, 20:4 was negatively correlated to grill flavor intensity, and off flavor intensity ($P < 0.05$).

To understand drivers of consumer overall liking, three stepwise regression analyses were conducted and reported in Tables 11, 12, and 13. The first analysis examined the relationship between raw chemical and fatty acid variables to predict consumer overall liking (Table 11). Variables included in the equation were significant ($P < 0.15$). Six variables were included in the equation and the equation accounted for 27 percent of the variation in consumer overall liking. Chemical lipid percentage was the first variable to enter the equation and five fatty acids entered as the second to sixth variables. Chemical lipid content is related to USDA QG, which is used to predict consumer palatability. Therefore, it was expected that chemical lipid content entered the equation for consumer overall liking. Fatty acid content has been related to beef flavor (Mottram and Edwards, 1983). While significant ($P < 0.05$), this equation was not strong and did not account for sufficient amount of variation to be used to predict consumer overall liking on a consistent basis.

Figure 2 showed the relationship between trained beef flavor descriptive attributes, consumer overall liking, fatty acid and chemical data. Fat-like, pH, myoglobin, 18:1 total trans, 17:0, and 15:0 clustered together indicating a relationship between these attributes. Non-heme iron was related to long chain fatty acids. Previous research by Yancey et al. (2006) suggested that muscles with higher concentrations of myoglobin and heme iron typically exhibited liver-like and metallic flavors. While it seems logical for these flavors to increase as the iron content increased, this research did not show strong correlations between myoglobin or non-heme iron content and liver-like, coinciding with findings from Meisinger et al. (2006). The medium chain fatty acids clustered with consumer overall liking. This supports research from Baublits et al. (2009). Liver-like and umami were closely related, as well as brown/roasted and bloody/serumy and the two groups clustered in opposite quadrants. Strong relationships were seen with beef identity and other attributes indicating that fatty acid, pH, non-heme iron and myoglobin did not strongly drive beef identity.

Volatile Aromatic Flavor Components

Table 12 defined the volatile aromatic compounds identified by the GC/MS system. The mean area under the curve for each compound was reported. There were 149 volatile compounds identified at the olfactory port by a trained panelist. In similar research, a greater number of compounds were found (Miller and Kerth, 2012). However, that research included more variation in storage, muscles and cooking parameters. These compounds were classified into nine categories to reduce the number of compounds and to see if major reactions drove differences in beef flavor: LLDP,

LRMP, LLDP:LMRP, sulfur-containing compounds, nitrogen-containing compounds, aldehydes, alcohols, ketones, acids, alkanes, alkenes, furans, pyrazines, benzenes, ring structures and straight chains. To further understand the relationships between volatile flavor categories and consumer overall liking and descriptive beef flavor attributes, principal component analyses were conducted (Figure 3).

The data presented in Table 13 indicated that Se BF roasts cooked to a high degree of doneness produced more LMRP compared to Choice or Se BF roasts cooked to a low degree of doneness, as well as grilled LM steaks and all of the high pH LM steaks ($P < 0.05$). It is no surprise that LMRP increased in samples cooked for an extended period of time to a high degree of doneness (Mottram, 1998). A trend existed ($P = 0.0615$) for LLDP to be higher in Choice steaks and roasts cooked to a lower degree of doneness compared to their high degree of doneness counterparts within a cooking method. The development of LLDP has been shown to be associated with either heat denaturation of lipid during cooking or lipid oxidation during storage (Mottram, 1998; Shahidi, 1994). As LLDP products are aldehydes, ketones and acids, it is not surprising the LLDP clustered with these compounds in Figure 3. Maillard reaction products have been shown to occur during cooking with high heat and extended cooking times (Mottram and Whitfield, 1994). Mottram (1998) indicated that during cooking the development of LLDP and LMRP products occur rapidly. In the presence of both LLDP and LMRP, LLDP products tend to contribute to flavor to a greater extent (Mottram, 1998). Therefore, a variable of the ratio of LLDP and LMRP products was calculated and presented.

In Table 13, all beef samples contained LMRP and LLDP. Table 13 showed that regardless of cooking method, LLDP products were present in greater concentrations than LMRP products, as expected based on previous research. Mottram (1998) discussed that lipid-derived volatiles are quantitatively dominant to flavor development unless harsh cooking methods cause extensive browning, in which the effects of the Maillard reaction would reign. The LLDP product level was not affected by internal temperature endpoint or cooking method to the same extent as LMRP product level. The ratio of LLDP:LMRP, alcohols, and ring structures were not significant ($P = 0.40$, 0.0543, and 0.2885, respectively) across cook treatments.

Sulfur compounds differed across cooking treatments and degrees of doneness ($P = 0.001$). Select BF roasts cooked to a high degree of doneness had the highest ($P < 0.05$) concentration of sulfur-containing compounds. Choice GM steaks cooked on the grill to a high degree of doneness and Ch BF roasts cooked to a high degree of doneness had a higher ($P < 0.05$) concentration of sulfur-containing compounds than high pH LM steaks, regardless of cooking method or degree of doneness. Figure 3 showed sulfur-containing compounds clustering with aldehydes, LMRP, benzene compounds, liver-like and Se BF roasts cooked to a high degree of doneness. Sulfur compounds, such as H_2S, can react with aldehydes to form dithiozines, thiols, sulphides, and trithianes (Shahidi, 1994).

Choice GM steaks cooked to a high degree of doneness on the grill produced more ($P < 0.05$) nitrogen-containing compounds than any other muscle/cooking treatment except for Choice LM steaks cooked on GF to a high degree of doneness ($P >$

0.05). The lower concentration of nitrogen-containing compounds in the high pH steaks most likely was due to the pH of the meat impacting heat denaturation. Trout (1989) showed that myoglobin did not denature at the same rate at a higher pH levels. In Figure 3, nitrogen-containing compounds expectantly clustered with Ch GM steaks cooked on the grill to a high degree of doneness, Ch LM steaks cooked on the GF to a high degree of doneness and pyrazines. Structurally, pyrazines are heterocyclic aromatic compounds that contain nitrogen. Therefore, it is logical that the two would cluster together in Figure 3. Brown/roasted, cardboardy, and salty loosely clustered with nitrogen-containing compounds. Since nitrogen-containing compounds are involved in amino acid degradation and the Maillard reaction, these relationships were understandable.

Select BF roasts cooked to a high degree of doneness had a higher ($P < 0.05$) concentration of aldehyde compounds compared to all other treatments except for Choice GM steaks cooked on GF to a low degree of doneness ($P > 0.05$). Aldehydes would be expected to be present at higher temperatures or extended cook times because they are a product of lipid-soluble components and water, and play a vital role in the Maillard reaction through Strecker degradation. In past research, aldehydes have been shown to influence the overall aroma profiles of cooked meat (Nursten, 1981). The interaction produced multiple hetercyclic compounds with long chain alkyl substituents, such as pyrazines, thiophenes, thiazoles, and thialzolines (Shahidi, 1994). This is reflected in Figure 3 as aldehyde compounds clustered between LLDP and LMRP, favoring LMRP. Aldehydes did not cluster with any descriptive flavor attributes.

Past research has shown alcohols to be formed by the decomposition of secondary hydroperoxides of fatty acids (Tanchotikul and Hsieh, 1989). As hydroperoxides develop with heating of lipids, cooking treatment would expectantly affect the level of secondary hydroperoxides and the level of alcohols developed during cooking. However, in Table 13, the levels of alcohols were not affected by cooking treatment ($P = 0.0543$) and alcohols did not cluster with any cooking treatments in Figure 3. Alcohol did cluster with bitter, bloody, alkane, alkene, and medicinal.

Choice BF roasts cooked to a low degree of doneness had a higher amount of ketone compounds compared to Ch BF roasts to a low degree of doneness, Ch LM steaks cooked to a high degree of doneness, high pH LM steaks cooked on the GF, and high pH LM steaks cooked on the grill to a high degree of doneness ($P < 0.05$). In Figure 3, ketone compounds closely clustered with acids, furans, Ch BF roasts cooked to a low degree of doneness, sour and sour dairy. In the dairy industry, the development of ketone compounds, such as heptan-2-one and nonan-2-one, are key in producing the blue cheese aroma. Other ketone compounds were noted for producing buttery aromas.

Closely related to ketones, acids were also affected by the different cooking treatments ($P < 0.05$). Ch LM steaks grilled to a low degree of doneness had a higher concentration of acid compounds than Ch LM steaks cooked to a high degree of doneness, as well as Ch BF roasts cooked to 80 °C, Se roasts cooked to 58 °C, and all high pH steaks regardless of cooking method or temperature ($P < 0.05$). While treatment effects were present, acid compounds did not closely cluster with any major beef flavor attributes in Figure 3, as expected through previous research (Grill et al., 1987).

Alkane and alkene compounds did not differ across treatments, but did closely cluster together, along with bitter, bloody and medicinal, as well as treatments with a low endpoint temperature in Figure 3. Kerth (2013) found that two lipid-derived alkane compounds decreased as cook surface temperature increased; however, this research did not support that.

Furans are heterocyclic aromatic compounds that are products of the Maillard reaction. The different treatments did not ($P = 0.3069$) impact the amount of furan compounds produced, however Ch BF roasts cooked to a low degree of doneness, along with acids and ketones, closely clustered with furan in Figure 3. Since furans alone do not greatly contribute to the flavor of meat (Grill et al., 1987), it is not surprising that the compounds did not closely cluster with any major flavor attributes (Figure 3). However, furans are able to react with cysteine, a sulfur-containing amino acid that have been shown to produce meaty aromas. Also, furans can produce lactones that may have sweet, dairy or waxy notes.

Pyrazines are known to have a cooked, roasted or toasted flavor (Calkins and Hodgen, 2007) and develop in meat exposed to high heat. As a product of the Strecker degradation and the Maillard reaction (Mottram and Whitfield, 1994), the level of pyrazines formed was dependent on reactant conditions, such as moisture content, temperature, pH, and time (Shahidi, 1994). In Table 13, pyrazines compounds did not ($P = 0.1592$) differ across the treatments as expected. In other research, Kerth (2013) was able to manipulate the amount of pyrazines in the sample through cooking surface temperature and steak thickness. Kerth (2013) found that as the temperature of the

cooking surface increased, the amount of pyrazines increased. In this research, pyrazines compounds clustered with brown/roasted, nitrogen-containing compounds, and Ch LM steaks cooked on the GF to a high degree of doneness. Due to the known flavor profile of pyrazines, the relationship with brown/roasted was expected (van Boekel, 2006). While brown roasted did not cluster with consumer overall liking in Figure 3, the flavor did cluster with consumer overall liking in Figure 1. Research by Lorenzen et al. (2005) studied the effects of endpoint temperature differences on sensory and instrumental beef flavor. This study observed a strong relationship between pyrazines and roasted, but, similarly, did not see a relationship with pyrazines and consumer overall liking.

Benzene is a six-carbon ring structure that is a product of the Maillard reaction and has a sweet aroma. Benzene compounds differed across the treatments ($P = 0.001$). Choice GM steaks cooked on the GF to 80 °C had greater ($P < 0.05$) concentrations of benzene compounds than the Ch GM steaks cooked on the GF to 58 °C, Ch and Se BF roasts cooked to 58 °C, Ch LM steaks cooked on the GF to 58 °C, Ch LM steaks cooked on the grill to 58 and 80 °C, and all high ph LM steaks. While Figure 3 did not show benzene clustering with sweet, the compound did show a strong relationship with LMRP and aldehydes.

Ring structures and straight compounds have been loosely associated with LMRP and LLDP, respectively (Shahidi, 1994). However, this generalization does not hold true for all compounds. As with the comparison between LMRP and LLDP, quantitatively there was a lower concentration of ring structures to straight compounds. Cooking treatments did not influence the production of ring structures ($P = 0.2885$), but did

impact the production of straight compounds ($P = 0.0493$). Select BF roasts cooked to a high degree of doneness had a greater concentration of straight compounds than Ch GM steaks cooked on the grill, Se BF roasts cooked to a low degree of doneness, and all Ch and high pH LM steaks, regardless of cooking method or degree of doneness ($P < 0.05$). In Figure 3, ring structures clustered most closely with alcohols, alkenes, medicinal, bitter, alkanes, sour dairy and Ch GM steaks cooked on the grill to 58 °C. Considering that not all ring structures are Maillard reaction products and lipid degradation products tend to be present in higher quantities, it makes sense that the ring structure compounds would cluster with the lipid derived alkane, alcohol, and alkene compounds. Straight compounds closely clustered with LLDP as anticipated.

Regression equations were calculated to determine what specific chemical compounds could be used to predict consumer overall liking (Table 14). To further understand the relationships between consumer overall liking and descriptive beef flavor attributes, principal component analysis was conducted (Figure 4). Twenty-two aromatic volatile chemicals accounted for 55 percent of consumer overall liking. Methanethiol (C55) was the first variable to enter this equation, followed by nonacosane (C26). Methanethiol is an alcohol that is known to be present in blood and has a putrid aroma. Nonacosane is an aroma volatile that has not been fully elucidated; however, it is a straight chain hydrocarbon compound containing 29 carbons. This compound was found in greater concentrations in ground beef with more fat compared to an extra lean sample (Rogge et al., 1991). The importance of nonacosane in this study could be related to modifications during heating. Furthermore, nonacosane was negatively related to overall

liking. Therefore as nonacosane increased, overall liking decreased. The third compound to enter the equation was 2,3-butanedione (C11). This compound is a product of lipid oxidation and has been shown to produce a buttery flavor. Together these three compounds accounted for about 18 percent of the total variation in the equation to predict overall liking. The 2-ethyl-3-methyl-pyrazine compound accounted for 4.8 percent of the variation in the equation to predict overall liking. Pyrazine compounds are a product of the Maillard reaction and are produced with high heat cookery. The production of these heteroatomic aroma compounds from the Maillard reaction prevent warmed over-flavor in beef (Shahidi, 1994), thus increasing overall liking. It is not surprising that compounds responsible for buttery and roasted flavors entered the equation for overall liking as these descriptive flavor attributes were most closely clustered with overall liking in Figure 1. The remaining compounds accounted for small amounts of variation and were a mixture of both Maillard reaction and lipid degradation products. This research coincided with original beef flavor research conducted by Batzer et al. (1960) that determined cooked meat flavor was the result of interactions between multiple compounds. In this research, one category of compounds was not driving overall liking, but these data indicated that compounds resulting from high heat cookery and lipid degradation are present when consumer rate beef higher for overall liking. These chemicals could be used to predict consumer acceptability for moderate to heavy beef-eaters.

In order to determine if the major volatiles influencing consumer overall liking were differing between the 16 treatments, analysis of variance was conducted and

presented in Table 15. Variables methanethiol (C55), nonacosane (C26), 2,3-butanedione (C11), heptane,1,1'oxybis (C94), ethanone, 1-(1H-pyrrol-2-yl)- (C44), pyrazine,2-ethyl-3-methyl- (C69) were selected as they either strongly entered the regression equation or closely clustered with consumer overall liking in Figure 4. Out of the six compounds, methanethiol (C55), 1,1'oxybis heptane, (C94), and 1-(1H-pyrrol-2-yl)-ethanone (C44) differed across treatments ($P < 0.05$). Methanethiol (C55) tended to be present in samples that were cooked to a high degree of doneness, however this did not hold true for all treatments including Ch and high pH LM steaks. As a sulfur-containing compound, it is expected to be present in higher concentrations as the endpoint temperature increased. Nonacosane and 2,3-butanedione did not differ among treatments ($P = 0.53$ and 0.23, respectively), but was present in all. As a product of lipid oxidation, 2,3-butanedione was expected to be present in greater quantities and was the most abundant out of the six compounds. 1,-1'oxybis heptane, differed across the treatments ($P < 0.05$) and was present in highest concentrations in Ch GM steaks cooked on a grill to a low degree of doneness. The two other treatments the compound was found in were Ch LM steaks cooked on the GF and grill to a low degree of doneness. 1-(1H-pyrrol-2-yl)-ethanone, differed across treatments ($P < 0.05$), but was not present in three treatments, including Ch BF roasts cooked to 80 °C, Se BF roasts cooked to 80 °C, and high pH LM steaks cooked on the grill to 80 °C. It was present in the highest concentrations in Ch GM steaks cooked on the grill to 80 °C. Finally, 2-ethyl-3-methyl pyrazine, is a compound produced by the Maillard reaction and was not present in some of the treatments that were designed to minimize non-enzymatic browning, such as Ch

and Se BF roasts cooked in the CP and Ch LM steaks cooked on the GF to a low degree of doneness.

To more thoroughly understand how individual volatile chemical compounds were related to major trained beef flavor descriptive attributes, stepwise regression equations were calculated for each of the major beef flavor description attributes and volatile chemical compounds. Regression equations for beef flavor identity (Table 16), brown/roasted (Table 18), bloody/serumy (Table 20), fat-like (Table 22), metallic (Table 24), liver –like (Table 26), and umami (Table 28) flavor attributes were presented. These equations accounted for 36, 32, 32, 31, 31, 24, and 60 percent of the variability in beef flavor identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, and umami beef flavor descriptive attributes, respectively. As with consumer overall liking, to determine if the volatiles influencing the major descriptive attributes were differing between the 16 treatments, analysis of variance was conducted for beef flavor identity (Table 17), brown/roasted (Table 19), bloody/serumy (Table 21), fat-like (Table 23), metallic (Table 25), liver –like (Table 27), and umami (Table 29) flavor attributes.

No single compound accounted for a high amount of variation in beef flavor identity (Table 16). The serumy flavor of raw meat does not taste or smell like cooked meat. However, raw and cook meat both are developed from the same initial flavor precursors (Shahidi, 1994). Wasserman (1979) determined that upon heating, these precursors react producing the series of complex volatile and non-volatile mixtures that are characteristic of meat aroma and taste. The first compound to enter the equation was sulfur dioxide (C51). Sulfur containing compounds have low thresholds and have been

shown to greatly contribute to meaty aromas (MacLeod, 1986). Sulfur dioxide, as well as 2,3-octanedione (C30), and 3-methyl-2-thiophenecarboxaldehyde (C75) also clustered with beef identity in Figure 2. 2,3-Octanedione is commonly found in beef as a product of lipid oxidation and has been seen in higher concentrations in warmed-over beef (Angelo et. al, 1987). 3-Methyl-2-thiophenecarboxaldehyde is a sulfuric compound that has a low odor threshold and is produced during the Maillard reaction. Together, these three compounds accounted for 2.72 percent of the variation in beef flavor. Furthermore, methanethiol (C55) loosely clustered with beef in the principal component analysis. Thiol compounds are the sulfur analogue of alcohols produced by the Maillard reaction and emit strong aromas. Wasserman (1979) indicated that increasing temperature resulted in lower thiol concentrations. The second compound to enter the regression equation and account for four percent of the variation was N-ethyl-ethanamine, (c111). This compound has not been frequently cited in meat flavor research and clustered opposite of beef in Figure 3. Interestingly, these data showed that beef identity was comprised of both Maillard and lipid oxidation products.

Table 17 showed the analysis of variance for the major contributor to beef flavor, sulfur dioxide (C51). Based on previously discussed research, sulfur-containing compounds are products of the Maillard reaction and have been shown to produce meat-like aromas. Therefore, it is not surprising that sulfur dioxide was not present in the treatments designed to create minimal Maillard reaction products. These treatments included: Ch GM steaks, Ch LM and high pH LM steaks cooked on the GF or grill to 58 °C, as well as Ch LM and high pH LM steaks cooked to 80 °C. In the case of the Ch

and high pH steaks cooked to 80 °C, it is not uncommon for marbling to interfere with the development of Maillard compounds (Mottram, 1998).

In Table 18, 1-(1H-pyrrol-2-yl)-ethanone, (C44) entered the equation first for brown/roasted. Interestingly, this compound also entered the stepwise regression equation for overall liking (Table 14). Figure 1 showed that brown/roasted and consumer overall liking were related. Pyrazines are a product of the Maillard reaction and are known for a distinctly roasted aroma. 2-ethyl-6-methyl pyrazine, entered the equation and accounted for 3.57 percent of the variation in brown/roasted flavor. Out of the ten compounds that entered the equation, two were sulfur-containing compounds. As previously mentioned, sulfur compounds are typically present at low levels, have low odor thresholds, and produce strong cooked meat aromas. In Figure 3, brown roasted most closely clustered with pyrazines, as expected knowing pyrazines compound's aroma profile.

The analysis of variance between the sixteen treatments and two compounds that entered the equation first for brown/roasted are listed in table 19. 1-(1H-pyrrol-2-yl)-ethanine (C44) accounted for eight percent in the variation of the equation to predict brown/roasted flavor and differed between the treatments ($P < 0.05$). This compound was present in highest concentrations in Ch GM steaks cooked on the grill to 80 °C. Compared to 3-methyl nonacosane (C97), 1-(1H-pyrrol-2-yl)- ethanine (C44) quantitatively dominated in the number of samples it was present in, as well as the overall root mean square error (RMSE) value. 3-methyl nonacosane (C97) was detected in two treatments: Ch GM steaks and high pH steaks grilled to a high degree of

doneness. While it did not differ across the treatments ($P = 0.07$), the absence of the chemical in a number of treatments indicated that the compound was produced when steaks are exposed to high surface temperatures.

Ten volatile compounds accounted for 33 percent of the variation in bloody/ serumy (Table 20). The first variable to enter the equation was dimethyl disulfide (C72). The reactions to produce sulfuric compounds were produced by amino acid side chains. Upon heating, these compounds can react with sugars and the Maillard reaction to form volatile sulfur containing compounds (Shahidi, 1994). Many of these sulfuric compounds, such as dimethyl disulfide greatly contribute to the meaty aroma of beef (MacLeod, 1986). Of the ten compounds, four were alcohols. The compounds present have been associated with lipid oxidation and heat denaturation, as well as Maillard reaction products. Therefore, higher quantities of these compounds would be expected. Compounds with negative ß values decreased as bloody/serumy increased. In Figure 4, bloody/serumy clustered most closely to 1-heptanal (C31) and 1-octanol (C19). Bloody/serumy would be higher in steaks that are cooked to lower internal cook temperature endpoints. These samples would have been subjected to less protein, lipid and heat denaturation. The categories of compounds that cluster with bloody/serumy were alcohols, alkenes, and alkanes. Of the compounds present, five compounds in the regression equation to predict bloody/serumy fit into one of these categories.

The analyses of variance between dimethyl disulfide (C72) and 1-heptanal (C31) and the 16 treatments are shown in Table 21. Dimethyl disulfide (C72) differed across treatments ($P < 0.05$) and was mainly present in samples that were cooked to a high

degree of doneness. The compound was most abundant in Se BF roasts cooked to 80 °C. While 1-heptanal did not differ ($P = 0.06$), it was present in all treatments.

Benzaldehyde (C6) accounted for 8.09 percent in the variation for the fat-like stepwise regression equation (Table 22). Benzaldehyde is a ring structure that is lipid-derived and is known to have almond oil, or burning aromatic taste (Calkins and Hodgen, 2007). The ß value was negative, indicating that as benzaldehyde increased, fat-like flavor decreased. Considering benzaldehyde was a product of lipid denaturation, these results indicated that fat-like flavor was rated higher in steaks and roasts with less benzaldehyde. Other notable compounds to enter the regression equation were octanol (C5), hexanoic acid (C9), 1-hexanol (C16), and thiobis, methane (C33). Octanol has been frequently reported in beef flavor studies and has a penetrating aromatic odor, fatty, waxy, citrus, oily, walnut, moss, chemical, metal or burnt aroma profile. Hecanoic acid is a carboxylic acid derived from hexane with an odor that is fatty, cheesy, and waxy. 1-Hexanol is common in meat samples and has a woody, cut grass, chemical-winey, fatty, fruity, or weak metallic aroma (Calkins and Hodgen, 2007). Thiobis, methane has not been commonly cited as a major contributor to beef flavor in previous research. However, the compound accounted for about four percent of the variation in the fat-like equation in this study.

The analysis of variance presented in Table 23 showed variation in concentrations of benzaldehyde (C6) among the treatments ($P < 0.05$). Choice GM steaks cooked on the GF to 80 °C had higher levels of benzaldehyde than the Ch GM steaks cooked on the GF to 58 °C, as did the Ch BF roasts cooked to 80 °C compared to

the Ch BF roasts cooked to 58 °C. Benzaldehyde levels did not differ amongst the Se BF roasts, Ch LM steaks and high pH LM steaks, however the high pH steaks overall had lower concentrations of the compound in comparison to the Ch GM cooked on the GF to 58 °C and the Ch BF roasts cooked to 80 °C. As previously mentioned, high pH steaks do not have the same myoglobin denaturation rate as normal pH steaks (Trout, 1989). Since this is a lipid-derived volatile compound, it makes sense that greater concentrations of benzaldehyde were not seen in steaks with high pH. In fact, Figure 3 showed LLDP clustered opposite of all the high pH treatments. The second compound analyzed was thiobis, methane (C33). Interestingly, this compound was present in all but one treatment and differed between treatments. Thiobis methane was higher in Ch BF roasts cooked to a low degree of doneness than Ch BF roasts cooked to a high degree of doneness, Se BF roasts, Ch LM steaks, and high pH steaks. The compound was not present in high pH steaks cooked to 58 °C.

Ten volatile chemical compounds were used in the final stepwise regression to account for 31.07 percent of the variability in metallic (Table 24). Many compounds used to predict metallic flavor were lipid oxidation or heat denaturation products. Decane-1,2-d2 was the first variable to enter the stepwise regression and accounted for five percent of the variation in the equation, while the second variable to enter the equation was nonenal (C22), both of which were products of lipid oxidation. Nonenal produces a green, fat-like aroma. In Figure 4, metallic clustered closest with this compound. 1-Butanol entered the stepwise regression and accounted for about three percent of the variation in the equation to predict metallic. Past research has linked this

compound to a green, malt aroma. The remaining compounds in the regression positively contributed to metallic flavor in beef and were all products of lipid degradation.

Table 25 showed that neither of the compounds analyzed differed across treatments ($P = 0.33$; $P = 0.51$), however nonenal (C22) was present in all compounds, while decane-1,2-d2 was not. Overall, nonenal was quantitatively dominant to decane-1,2-d2. Decane was not present in Se BF roasts or samples cooked on the GF.

Notable compounds to enter the stepwise regression equation and contribute to liver like flavor (Table 26) were Heptanal (C4), 1-butanol (C13), 1-heptanol (C31), 1-octen-3-ol (C36), and 2-nonenal,(E)- (C43). All were products of lipid oxidation and have been known to contribute to liver-like flavor (Calkins and Hodgen, 2007). Calkins and Hodgen (2007) found that hexanal, hexanol, 1-octen-3-ol, and nonanal were common lipid-derived chemical volatiles found in liver-like samples. The aforementioned compounds all have a green, fatty, or unpleasant aroma. 1-Octen-3-ol has also been known to emit a mushroom aroma. 2- nonenal,(E) is known for a cardboardy or fat-like aroma (Shahidi, 1994). While predominantly lipid derived volatiles entered the step-wise regression, the Calkins and Hodgen (2007) research was not able to attribute liver-like flavor solely to lipid oxidation. Dimethyl disulfide (72) entered the equation and clustered with liver-like in Figure 4. Dimethyl disulfide is a sulfur containing compound that is a result of amino acid degradation through the Maillard reaction. This compound primarily contributes to meaty aromas, but can produce a green, vegetable like, or sulfurous aroma, and can impart aromas at low

concentrations due to a low threshold value (Shahidi, 1994). In the regression equation (Table 26), the ß values was negative, indicating that as dimethyl, disulfide increased, liver-like decreased.

Heptanal (C4), 2,3-octanedione (C30), and dimethyl, disulfide (C72) were included in the analysis of variance across the 16 different treatments (Table 27). As expected, heptanal was present in all treatments, but did not differ ($P = 0.74$). Calkins and Hodgen (2007) found higher levels of heptanal in the *M. Triceps brachii* that was liver-like as compared to the normal *M. Triceps brachii* steaks. In Figure 4, heptanal was loosely clustered with liver-like. Internal steak temperature impacted the heptanal level in a study conducted by Kerth (2013). Larick et al (1987) found higher levels of heptanal in grass-fed beef as compared to grain-fed, and their concentration decreased with grain-feeding. Furthermore, Larick et al. (1987) related heptanal to grass-fed flavor in ground-beef and the flavor was enhanced with specific cooking methods (oven broiling versus cooking in a beaker where the meat juices accumulated for ground beef). However, grass-fed beef was not a variable in this study. Like heptanal, 2,3-octanedione (C30) was present in all treatments, but did not differ between the treatments. In research investigating warmed over flavor in beef, 2,3-Octanedione was highly correlated with 2-thiobarbituric acid (TBA) numbers and rancid, metallic, cardboard and stale. However, warmed-over flavor was not a variable in this study. Dimethyl disulfide (C72) was the final variable analyzed for differences across treatments for liver-like, and was the only variable that differed ($P < 0.05$). The compound was highest in Se BF roasts cooked to 80 °C and was not present in Ch GM steaks, Se BF roasts, and Ch LM steaks cooked to

58 °C, as well as high pH steaks cooked on the GF to 58 °C, and on the grill to 58 and 80 °C. As a product of the Maillard reaction, the compound was expected to be present in greater quantities in treatments selected to induce non-enzymatic browning.

The stepwise regression equation for umami was presented in Table 28 and was the most highly predictive flavor attribute. Twenty-nine variables were included in the final equation and accounted for 60 percent of the variation in umami. Table 28 showed that the first variable to enter the equation for umami was 1-octanol (C18). Interestingly, as a product of lipid oxidation, this compound is known for having a soapy aromatic. Kerth (2013) found that 1-octanol increased as cook surface temperature decreased. It was not surprising to see 2-ethyl-3-methyl pyrazine, a Maillard reaction product, included in the equation as well. Umami is an interesting attribute in that it can modify flavor perception. Research has identified 5' nucleotides such as 5'inosinate and 5'-guanylate as being characteristic of umami flavor (Shahidi, 1994). Shahidi (1994) also explained that previous research showed compounds contributing to umami flavor decreased as internal temperature increased. Furthermore, glutamate (contributor to umami flavor) was low when meat was cooked in water. These cooking treatments could account for some of the variation seen in this study. Umami did not closely cluster with any attributes in Figure 4.

Least square means were calculated for four compounds influencing umami flavor across the 16 treatments (Table 29). Of the four compounds, 1-octanol (C19) was the only one to differ ($P < 0.05$). Choice GM steaks cooked to a low degree of doneness, Ch LM steaks cooked on the GF to 58 °C, and high pH steaks cooked on the grill to

58 °C had a greater amount of 1-octanol when compared to Ch BF roasts cooked to 80 °C, Se BF roasts and Ch LM steaks cooked on the grill to 80 °C. As a product of lipid degradation, it is not surprising that the compound was present in all samples and tended to be present in greater concentrations in treatments designed to minimize the development of Maillard reaction products. Sulfur dioxide was not present in Ch GM steaks cooked to 58 °C and all of the and high pH LM steaks. As a sulfuric compound, oxamide,N-(methylthio)carbonyl would be expected to be present in greater quantities in samples that are cooked to higher degrees of doneness and with higher cooking surface temperatures. However, the compound did not follow that trend. Finally, hexanoic acid, pentlyester (C82) was not present in Ch GM steaks cooked to 58 °C on the grill, Ch BF roasts cooked to 58 °C, and Ch LM steaks cooked on the grill to 58 °C.

These aromatic chemical attributes can be used to predict beef flavor attributes. While it is not practical to measure each of these attributes for every piece of beef cooked or served, examination of treatments or conditions that affect or increase aromatic compounds related to beef identity, browned/roasted, bloody/serumy, fat-like and umami would influence final beef flavor.

Consumer One-On-One Interviews

In one-on-one interviews, consumers indicated that flavor was extremely important to them when eating beef. They also did not segment tenderness, juiciness and flavor as separate attributes. Neely et al. (1998) and Parrish et al. (1991) found that consumer's perception of taste had not changed over the past two decades. Consumers, in general, indicated that they liked grilled flavor in their beef and they disliked steaks

with a chewy texture (high pH LM, low degree of doneness). All segments of consumers indicated that they least preferred the sample that was very bland (beef BF roasts cooked in the CP). They liked beef because it was versatile, healthy and easy to prepare. Portland residents were typically more concerned with how the beef was raised (natural, organic, grass-fed) than consumers from Olathe. Consumers from Kansas were more knowledgeable of quality grades in comparison to Portland, Houston and Philadelphia consumers.

CHAPTER V

CONCLUSIONS

Different aromatic volatiles that are characteristic of various beef lexicon attributes, as well as different flavors identified in the beef lexicon can be manipulated by muscle, quality grade, pH level, cooking method and final internal temperature endpoint. These results provided highly predictive regression equations that identified the compounds responsible for major positive beef sensory flavor attributes. Not one single compound was highly predictive of a single beef flavor attribute. Nevertheless, chemical compounds classified as LMRP and LLDP were responsible for specific beef flavor components and were related to consumer sensory attributes. It would have been ideal to find one or two chemical compounds, or classifications of chemical compounds, that were responsible the major beef sensory flavor descriptive attributes. Even so, this research identified groups of volatile flavor compounds that may help to narrow down what compounds can be used to drive flavor differences.

Ultimately, this research could be used to improve the overall flavor of beef presented to consumers for products not acceptable in flavor. For example, roasts cooked in crock-pots and high pH steaks produced unacceptable eating experiences. One way to improve the roasts would be to sear the outside prior to moist hear cookery, producing more favorable Maillard reaction products. It would be ideal to identify consumer segments and then be able to give specific cookery instructions to generate volatile aromatic compounds and flavors that match the consumer's fancy. So far, data from this

research showed that high heat or extended cookery increases the production of Maillard reaction products, thus increasing overall liking. This research has made progress in answering the challenge to improve understanding of beef flavor.

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APPENDIX A

TABLES

Table 1. Definition and reference standards for meat descriptive flavor aromatics and basic taste sensory attributes and their intensities where [1]0 = none; 15 = extremely intense from Adhikari et al. (2011).

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid (hexanoic acid) = 12.0
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/serumy	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum based product such as charcoal liter fluid.	Zip-Loc sandwich bag = 13.0 Clorox in water = 6.5

Table 1. Continued.

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Cocoa	The aromatics associated with cocoa beans and powdered cocoa And chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5 (flavor)
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Mini Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc	Hexanal in propylene glycol (5,000 ppm) = 6.5 (aroma) Fresh parsley water = 9.0
Green-hay	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves	Dry parsley in medium snifter = 5.0 (aroma) Dry parsley in ~30-mL cup = 6.0
Leather	Musty, old leather (like old book bindings)	2,3,4-Trimethoxybenzaldehyde = 3.0 (aroma)
Liver-like	The aromatics associated with cooked organ meat/liver	Beef liver = 7.5 Braunschweiger liver sausage = 10.0 (must taste and swallow)

Table 1. Continued.

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (aroma)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 min at high) = 9.0
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese = 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)

Table 1. Continued.

Sensory Attribute	Definition	Reference, standard flavor scale value unless otherwise defined
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	A product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0
Other attributes Smoky – charcoal, smoky – wood, buttery, refrigerator-stale, soapy, barnyard, heated oil, asparagus, cumin, floral, beet and petroleum-like		

Table 2. Beef flavor attribute least squares means for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Umami	Basic Taste			
								Sweet	Sour	Salty	Bitter
P – value[i]	<0.001	<0.001	<0.001	<0.001	<0.001	0.17	<0.001	<0.001	<0.001	<0.001	<0.001
Choice GM steaks											
GF, 58 °C	9.4^{ab}	0.9^{abcd}	3.3^{e}	1.4^{de}	2.8^{d}	0.1^{a}	0.3^{a}	0.2^{a}	2.6^{e}	1.2^{bc}	1.9^{b}
GF, 80 °C	10.2^{bcd}	1.1^{bcd}	1.7^{b}	0.9^{ab}	2.1^{bc}	0.1^{ab}	0.7^{b}	0.5^{b}	2.1^{de}	1.2^{b}	1.7^{b}
Grill, 58 °C	9.7^{abc}	1.1^{bcd}	3.0^{e}	1.5^{de}	2.9^{d}	0.1^{a}	0.2^{a}	0.3^{ab}	2.7^{e}	1.2^{bc}	1.8^{b}
Grill, 80 °C	11.6^{f}	2.5^{e}	1.7^{b}	1.0^{abcd}	2.1^{b}	0.0^{a}	0.9^{bc}	0.5^{b}	2.1^{d}	1.2^{bc}	1.6^{b}
Choice BF roasts											
CP, 58 °C	9.9^{bc}	0.5^{a}	2.7^{de}	1.1^{bcd}	2.6^{d}	0.3^{ab}	0.8^{bc}	0.6^{bc}	2.2^{de}	1.3^{bc}	1.7^{b}
CP, 80 °C	11.0^{def}	1.2^{cd}	1.1^{ab}	1.0^{abc}	1.7^{a}	0.2^{ab}	1.2^{c}	0.7^{bc}	1.4^{bc}	1.4^{c}	1.3^{a}
Select BF roasts											
CP, 58 °C	9.2^{a}	0.4^{a}	2.3^{ce}	1.0^{abc}	2.5^{c}	0.0^{a}	0.7^{b}	0.4^{ab}	2.5^{e}	1.3^{bc}	1.8^{b}
CP, 80 °C	11.3^{ef}	0.9^{abcd}	0.9^{a}	1.0^{abc}	1.7^{a}	0.4^{b}	1.3^{c}	0.7^{bc}	1.4^{bc}	1.2^{b}	1.4^{ab}

Table 2. Continued.

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Umami	Basic Taste			
								Sweet	Sour	Salty	Bitter
Choice LM steak											
GF, 58 °C	10.1^{bcd}	0.8^{abc}	2.5^{de}	1.3^{cd}	2.6^{cd}	0.0^{a}	0.5^{ab}	0.6^{bc}	2.1^{de}	1.3^{bc}	1.5^{ab}
GF, 80 °C	10.8^{def}	0.9^{abcd}	1.6^{b}	1.2^{cd}	2.0^{ab}	0.4^{b}	1.1^{c}	0.6^{bc}	2.0^{cd}	1.3^{bc}	1.5^{ab}
Grill, 58 °C	10.4^{cde}	1.4^{d}	2.7^{e}	1.5^{de}	2.5^{cd}	0.0^{a}	0.6^{ab}	0.5^{bc}	2.2^{de}	1.3^{bc}	1.4^{ab}
Grill, 80 °C	11.4^{ef}	2.2^{e}	1.8^{b}	1.3^{d}	2.2^{b}	0.1^{a}	1.1^{c}	0.8^{c}	1.7^{c}	1.5^{bc}	1.6^{b}
High pH LM steaks											
GF, 58 °C	8.8^{a}	0.6^{ab}	2.7^{e}	1.6^{e}	2.2^{bc}	0.0^{a}	0.4^{ab}	0.7^{bc}	1.3^{ab}	1.0^{ab}	1.6^{b}
GF, 80 °C	9.7^{abc}	1.0^{abcd}	1.5^{ab}	1.3^{d}	1.6^{a}	0.2^{ab}	0.5^{ab}	0.6^{bc}	1.3^{bc}	1.0^{ab}	1.7^{b}
Grill, 58 °C	8.8^{a}	0.6^{ab}	2.7^{e}	1.6^{de}	2.2^{bc}	0.0^{a}	0.3^{ab}	0.6^{bc}	1.3^{b}	1.0^{a}	1.7^{b}
Grill, 80 °C	11.1^{def}	2.1^{e}	1.6^{b}	1.9^{e}	1.7^{a}	0.0^{a}	0.8^{bc}	0.8^{c}	0.9^{a}	1.2^{bc}	1.4^{ab}

Table 2. Continued.

Treatment	Overall Sweet	Cardboardy	WOF	Sour Dairy
P – value[i]	<0.001	0.01	0.25	<0.001
Choice GM steaks				
GF, 58 °C	0.4[a]	0.0[a]	0.0	0.1[b]
GF, 80 °C	0.7[abc]	0.2[ab]	0.1	0.0[ab]
Grill, 58 °C	0.4[a]	0.1[ab]	0.0	0.2[b]
Grill, 80 °C	0.6[abc]	0.2[ab]	0.1	0.0[ab]
Choice BF roasts				
CP, 58 °C	0.5[abc]	0.3[b]	0.1	0.0[ab]
CP, 80 °C	0.9[c]	0.2[ab]	0.2	0.0[ab]
Select BF roasts				
CP, 58 °C	0.5[ab]	0.3[b]	0.0	0.2[ab]
CP, 80 °C	0.9[c]	0.3[ab]	0.2	0.0[ab]

Table 2. Continued.

Treatment	Overall Sweet	Cardboardy	WOF	Sour Dairy
Choice LM steak				
GF, 58 °C	0.5[abc]	0.2[ab]	0.0	0.0[ab]
GF, 80 °C	0.6[abc]	0.2[a]	0.1	0.0[ab]
Grill, 58 °C	0.7[abc]	0.0[ab]	0.0	0.0[ab]
Grill, 80 °C	0.9[c]	0.0[ab]	0.0	0.0[ab]
High pH LM steaks				
GF, 58 °C	0.7[bc]	0.2[ab]	0.1	0.0[ab]
GF, 80 °C	0.7[abc]	0.3[b]	0.1	0.0[a]
Grill, 58 °C	0.8[bc]	0.1[ab]	0.1	0.0[a]
Grill, 80 °C	1.0[c]	0.2[ab]	0.0	0.0[ab]
RMSE[h]	0.33	0.23	0.16	0.10

[abcdef] Mean values within a column and effect followed by the same letter are not significantly different (P > 0.05).
[g] Aroma measured where 0 = none and 15 = extremely intense.
[h] Root Mean Square Error.
[i] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 3. Profile of consumers that participated in this study.

Demographic Characteristic	Number	Percent
City		
Houston	58	19.27%
Olathe	80	26.58%
Philadelphia	83	27.57%
Portland	80	26.58%
Gender		
Male	142	47.18%
Female	159	52.82%
Age, years		
< 20	11	3.65%
21 - 25	71	23.59%
26 - 35	76	25.25%
36 - 45	38	12.62%
46 - 55	35	11.63%
56 - 65	34	11.30%
>66	14	4.65%
Income, per year		
< $25,000	66	21.93%
$25,001 - $49,999	67	22.26%
$50,000 - $74,999	67	22.26%
$75,000 - $99,999	39	12.96%
> $100,000	61	20.27%
Food Allergies		
Yes	11	4.98%
No	209	94.57%
Protein Consumption		
Chicken		
Yes	219	99.10%
No	1	0.45%
Beef		
Yes	221	100.00%
No	0	0.00%
Pork		
Yes	206	93.21%
No	15	6.79%

Table 3. Continued.

Demographic Characteristic	Number	Percent
Fish		
Yes	198	89.59%
No	23	10.41%
Lamb		
Yes	148	67.27%
No	72	32.73%
Eggs		
Yes	209	94.57%
No	12	5.43%
Soy		
Yes	99	54.79%
No	120	45.21%
Beef Consumption Frequency		
Daily	20	6.67
5 or more times per week	70	23.33%
3 or more times per week	187	62.33%
Once per week / weekly	19	6.33%
Once every 2 weeks	2	0.67%
Less than once every 2 weeks	2	0.67%
Beef Purchasing Habits		
Grass Fed		
Yes	53	17.28%
No	249	82.72%
Dry Aged		
Yes	15	4.98%
No	286	95.02%
Traditional		
Yes	253	84.05%
No	48	15.95%
Organic		
Yes	51	18.27%
No	246	81.73%

Table 4. Least squares means for consumer attributes for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	Overall like/dislike	Flavor like/dislike	Beef flavor like/dislike	Beef flavor intensity	Grill flavor like/dislike	Grill flavor Intensity	Off-flavor Intensity
P – value[h]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Choice GM steaks							
GF, 58 °C	5.8[c]	5.8[cd]	6.0[c]	5.6[bc]	4.9[bc]	4.4[bc]	4.8[bc]
GF, 80 °C	5.2[b]	5.2[bc]	5.5[bc]	5.5[b]	4.7[bc]	4.3[bc]	4.4[ab]
Grill, 58 °C	6.8[e]	6.9[e]	7.0[e]	6.9[d]	6.4[de]	6.2[e]	5.6[cd]
Grill, 80 °C	6.0[cd]	6.1[d]	6.3[cd]	6.3[cd]	6.3[de]	6.0[e]	5.2[c]
Choice BF roasts							
CP, 58 °C	4.8[ab]	5.0[b]	5.3[ab]	5.2[ab]	4.2[ab]	3.8[ab]	4.3[ab]
CP, 80 °C	4.8[ab]	5.0[ab]	5.3[ab]	5.3[ab]	4.6[b]	4.1[b]	4.3[ab]
Select BF roasts							
CP, 58 °C	4.8[ab]	4.9[ab]	5.0[ab]	5.0[a]	3.9[a]	3.4[a]	4.2[ab]
CP, 80 °C	4.5[a]	4.5[a]	4.8[a]	5.0[a]	3.9[a]	3.4[a]	4.0[a]

Table 4. Continued.

Effect	Overall like/dislike	Flavor like/dislike	Beef flavor like/dislike	Beef flavor intensity	Grill flavor like/dislike	Grill flavor Intensity	Off-flavor Intensity
Choice LM steak							
GF, 58 °C	6.2[d]	6.1[d]	6.2[cd]	6.1[c]	5.4[c]	4.9[cd]	5.2[c]
GF, 80 °C	5.7[c]	5.7[cd]	6.0[c]	6.1[c]	5.1[c]	4.6[c]	4.9[bc]
Grill, 58 °C	7.3[f]	7.2[e]	7.2[e]	6.9[d]	7.2[e]	6.8[f]	5.6[cd]
Grill, 80 °C	6.8[e]	6.8[e]	6.7[de]	6.7[d]	6.8[e]	6.6[f]	5.7[d]
High pH LM steaks							
GF, 58 °C	5.6[bc]	5.3[bc]	5.5[b]	5.4[ab]	5.1[c]	6.4[bc]	4.7[bc]
GF, 80 °C	5.5[bc]	5.4[bc]	5.7[bc]	5.3[ab]	4.8[bc]	4.2[bc]	4.5[b]
Grill, 58 °C	5.7[c]	5.6[c]	5.8[bc]	5.7[bc]	5.5[c]	5.1[d]	4.7[bc]
Grill, 80 °C	6.5[de]	6.3[de]	6.5[d]	6.2[cd]	6.3[d]	6.0[e]	5.5[cd]
RMSE[g]	6.5	2.02	1.99	2.03	2.00	2.13	2.12

[abcdef] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[g] Root Mean Square Error.
[h] P - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 5. Simple correlation coefficients[a] between consumer sensory attributes and trained descriptive sensory panel flavor attributes.

Effect	Overall like/dislike	Flavor like/dislike	Beef flavor like/dislike	Beef flavor intensity	Grill flavor like/dislike	Grill flavor Intensity	Off-flavor Intensity
Flavor attributes							
Beef identity	0.05	0.07	0.07	0.11	0.14	0.21	0.16
Brown/roasted	0.27	0.26	0.27	0.25	0.40	0.46	0.32
Bloody/serumy	0.22	0.23	0.23	0.16	0.13	0.11	0.17
Fat-like	0.34	0.26	0.27	0.21	0.31	0.31	0.29
Metallic	0.11	0.15	0.16	0.13	0.02	0.04	0.13
Liver-like	0.18	0.16	0.16	0.09	0.19	0.17	0.07
Umami	0.13	0.10	0.11	0.05	0.04	0.01	0.08
Overall sweet	0.08	0.04	0.02	0.00	0.12	0.15	0.07
Sweet	0.10	0.08	0.08	0.08	0.16	0.18	0.09
Sour	0.08	0.17	0.17	0.18	0.00	0.01	0.09
Salty	0.15	0.20	0.16	0.19	0.11	0.17	0.19
Bitter	0.01	0.02	0.02	0.03	0.08	0.08	0.03
Musty-earthy/humus	0.00	0.03	0.05	0.06	0.06	0.07	0.00
Cardboardy	0.10	0.11	0.08	0.01	0.08	0.10	0.12

[a] Simple correlation coefficients > 0.15 is significant ($P < 0.05$).

Table 6. Stepwise linear regression for prediction of consumer overall liking as the dependent variable and consumer attributes as independent variables.

Step	Variables[a]	Estimate[b]	Partial R^2	Equation R^2
	Intercept	0.07		0.90
1	Flavor Like/Dislike	0.66	0.89	
2	Grill Like/Dislike	0.15	0.01	
3	Grill Flavor Intensity	0.40	0.01	
4	Beef Flavor Intensity	-0.22	0.001	

[a] Variables measured using 9-point hedonic and intensity scales were 1 = extremely dislike or none; 9 = extremely like or extremely intense.

[b] Estimates are the b-values for the final regression equation when the defined variable was included.

Table 7. Least squares means for chemical components for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	pH	Non-Heme iron, mg/g	Myoglobin mg/g	Moisture %	Lipid %
P – value[e]	<0.001	<0.001	<0.001	0.32	0.03
Choice GM steaks	5.70[a]	3.35[b]	3.02[b]	72.65	3.04[a]
Choice BF roasts	5.70[a]	3.25[a]	2.99[ab]	70.94	5.37[b]
Select BF roasts	5.68[a]	3.35[b]	2.89[a]	71.82	3.36[ab]
Choice LM steaks	5.70[a]	3.20[a]	3.18[c]	69.83	6.06[b]
High pH LM steaks	6.37[b]	3.22[a]	3.09[bc]	72.37	4.19[ab]
RMSE[d]	0.09	0.06	0.14	3.30	2.34

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error.
[e] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*

Table 8. Least squares means for fatty acid components for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	14:0	14:1	16:0	16:1	17:0	17:1	18:0	18:1 Cis 9	18:1 Cis 11	18:2	Total Trans
P – value[d]	0.14	0.03	0.27	<0.001	0.61	0.29	<0.001	<0.001	0.27	<0.001	0.01
Choice GM steaks	2.60	0.41[a]	24.39	2.03[a]	1.25	0.60	16.13[b]	30.10[a]	1.23	8.21[b]	5.19[b]
Choice BF roasts	2.46	0.83[b]	23.06	3.13[b]	1.22	1.09	12.05[a]	38.53[c]	0.72	5.81[ab]	3.25[a]
Select BF roasts	2.93	0.66[b]	23.76	3.06[b]	1.09	0.80	12.73[a]	34.16[b]	3.87	7.51[b]	4.38[ab]
Choice LM steak	3.05	0.63[ab]	24.70	2.94[b]	1.26	0.84	13.94[ab]	35.86[b]	0.82	4.53[a]	5.57[b]
High pH LM steaks	2.80	0.59[ab]	23.91	3.06[b]	1.30	0.93	14.97[b]	34.82[b]	1.03	4.07[a]	5.70[b]
RMSE[e]	0.54	0.27	1.69	0.61	0.31	0.01	2.11	4.22	0.54	2.24	1.63

Table 8. Continued.

Effect	15:0	20:4	20:5	24:0	22:6
P – value[d]	0.25	<0.001	0.70	0.55	0.04
Choice GM steaks	0.44	2.12[a]	0.05	0.29	0.23[a]
Choice BF roasts	0.45	1.36[a]	0.090	.19	0.26[a]
Select BF roasts	0.44	1.69[a]	0.070	.24	0.26[a]
Choice LM steak	0.50	0.67[b]	0.11	0.35	0.11[b]
High pH LM steaks	0.53	0.87[b]	0.11	0.12	0.23[a]
RMSE[e]	0.11	0.61	0.06	0.19	0.12

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] *P* - value from analysis of variance tables.
[e] Root Mean Square Error.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*

Table 9. Simple correlation coefficients[a] between fatty acid composition and trained descriptive sensory panel flavor attributes.

Effect	Beef	Brown/ Roasted	Bloody/ Serumy	Fat-Like	Metallic	Livery	Overall Umami	Sweet	Sweet	Sour	Salty
14:0	0.02	-0.04	-0.05	0.05	-0.09	0.08	0.14	0.10	0.11	-0.06	0.11
14:1	0.04	-0.14	-0.14	0.02	-0.01	0.14	0.13	-0.00	0.12	-0.15	0.16
15:0	-0.07	0.06	-0.06	0.16	-0.17	-0.08	0.02	0.18	0.27	-0.20	-0.01
16:0	0.03	0.04	0.04	0.09	-0.03	0.17	0.15	0.15	0.01	0.08	0.12
16:1	-0.00	-0.13	-0.09	0.09	-0.18	0.01	0.12	0.17	0.28	-0.31	0.00
17:0	-0.04	0.15	-0.01	0.12	-0.08	-0.06	-0.02	0.20	0.18	-0.07	0.02
17:1	-0.02	0.01	-0.10	0.04	-0.18	-0.08	0.07	0.14	0.31	-0.25	-0.02
18:0	-0.06	0.09	0.11	0.16	0.02	0.03	-0.12	0.07	-0.15	0.05	-0.13
18:1 Cis 9	0.06	-0.04	-0.09	0.03	-0.16	-0.07	0.08	0.10	0.28	-0.23	0.01
18:1 Cis 11	-0.18	-0.07	0.08	0.05	0.07	-0.20	-0.25	-0.20	-0.22	0.06	-0.19
18:2	0.01	-0.00	0.05	-0.29	0.26	0.10	0.00	-0.21	-0.31	0.36	0.06
20:4	-0.06	0.01	0.08	-0.22	0.25	0.11	-0.07	-0.19	-0.32	0.31	-0.00
20:5	-0.13	-0.01	0.05	0.20	-0.02	0.01	-0.14	-0.04	0.13	-0.12	-0.11
24:0	-0.04	-0.12	0.07	-0.15	0.12	-0.02	0.01	-0.16	-0.12	0.20	0.12
22:6	-0.16	-0.04	-0.00	0.01	0.07	0.07	-0.11	-0.13	-0.06	0.03	-0.15
Total Trans	0.01	0.07	0.03	0.07	-0.09	-0.07	-0.02	0.07	0.02	-0.04	0.02

Table 9. Continued.

Effect	Bitter	Card-boardy	Warmed Over	Sour Milk
14:0	0.06	-0.00	-0.03	-0.08
14:1	-0.06	-0.03	-0.03	-0.16
15:0	0.01	-0.04	-0.11	-0.03
16:0	0.15	0.08	0.05	0.07
16:1	-0.13	0.00	-0.02	-0.30
17:0	-0.01	0.03	-0.06	0.04
17:1	-0.12	0.01	-0.07	-0.18
18:0	0.12	0.09	0.11	0.20
18:1 Cis 9	-0.14	-0.02	0.03	-0.28
18:1 Cis 11	0.06	-0.22	-0.14	0.09
18:2	0.07	0.03	0.08	0.25
20:4	0.08	0.04	0.06	0.27
20:5	-0.15	-0.12	-0.22	-0.12
24:0	0.06	-0.05	-0.07	0.01
22:6	0.07	0.03	0.05	0.12
Total Trans	0.06	-0.05	-0.16	-0.02

[a] Simple correlation coefficients > 0.15 is significant ($P < 0.05$).

Table 10. Simple correlation coefficients[a] between fatty acid composition and consumer sensory attributes.

Effect	Overall like/dislike	Flavor like/dislike	Beef flavor like/dislike	Beef flavor intensity	Grill flavor like/dislike	Grill flavor Intensity	Off-flavor Intensity
14:0	0.14	0.10	0.04	0.03	0.06	0.07	0.03
14:1	-0.10	-0.13	-0.13	-0.08	0.13	-0.11	-0.01
15:0	0.13	0.07	0.05	0.01	0.10	0.09	0.00
16:0	0.19	0.17	0.11	0.11	0.14	0.13	0.04
16:1	-0.08	0.09	-0.12	-0.12	-0.08	-0.08	-0.03
17:0	0.12	0.11	0.11	-0.11	0.12	0.12	0.01
17:1	-0.11	-0.11	-0.11	-0.10	-0.08	-0.07	-0.10
18:0	0.16	0.14	0.13	0.13	0.17	0.14	0.05
18:1 Cis	-0.07	-0.05	-0.05	-0.04	-0.03	-0.04	-0.01
18:1 Cis	0.02	0.03	0.03	-0.02	-0.00	-0.01	0.00
18:2	-0.19	-0.13	-0.09	-0.08	-0.16	-0.13	-0.11
20:4	-0.21	-0.18	-0.13	-0.13	-0.19	-0.17	-0.17
20:5	0.14	0.12	0.09	0.01	0.15	0.10	0.06
24:0	-0.00	0.02	0.00	-0.02	-0.02	0.01	-0.02
22:6	-0.25	-0.25	-0.21	-0.24	-0.26	-0.26	-0.20
Total Trans	0.31	0.27	0.23	0.20	0.23	0.23	0.19

[a] Simple correlation coefficients > 0.15 is significant ($P < 0.05$).

Table 11. Stepwise linear regression for prediction of consumer overall liking as the dependent variable and chemical data as independent variables.

Variables	Estimate[b]	Partial R^2	Equation[a] R^2
Intercept	5.78		0.27
Lipid, percentage	0.054	0.05	
16:1	0.47	0.01	
17:1 cis	-0.71	0.01	
17:1 trans	-11.32	0.01	
18:1 trans 9	0.11	0.05	
18:1	-0.09	0.03	

[a] Estimates are the b-values for the final regression equation when the defined variable was included.

Table 12. Overall means, standard deviation, minimum and maximum values for volatile, aromatic chemicals identified by the GC/MS.

Code:	Volatile, Aromatic Chemical	n	Mean	Standard Deviation
C 1 :	dioxime ethanedial	149	150.5	623.7
C 2 :	Octanoic acid	149	2322.0	4129.8
C 3 :	Hexanal	149	825898.8	1569756.3
C 4 :	Heptanal	149	7324.9	35965.0
C 5 :	Octanal	149	202922.7	170100.7
C 6 :	Benzaldehyde	149	386668.6	337378.6
C 7 :	Nonanal	149	512194.7	355173.6
C 9 :	Hexanoic acid	149	55887.4	78283.5
C 10 :	4-methyl-3-Pentenoicacid	149	1544.0	6767.5
C 11 :	2,3-Butanedione	149	68224.9	131601.5
C 12 :	Pentanal	149	49516.4	80928.3
C 13 :	1-Butanol	149	79152.5	114702.8
C 14 :	3-hydroxy-2-Butanone	149	337061.5	313423.3
C 15 :	N-Heptanal	149	263220.7	287958.1
C 16 :	1-Hexanol	149	15587.1	26281.2
C 17 :	2-pentyl-furan	149	22753.3	39470.8
C 18 :	dl-Limonene	149	49022.4	146762.3
C 19 :	1-Octanol	149	37889.2	33095.3
C 20 :	Dodecane	149	60875.3	200727.9
C 21 :	Phenyl-actaldehyde	149	2856.8	5768.6
C 22 :	Nonenal	149	10291.4	24472.5
C 23 :	1,3-bis(1,1-dimethylethyl)-benzene	149	15512.1	22405.0
C 24 :	Dodecanal	149	3819.6	10180.2
C 25 :	Tridecanal	149	2718.5	5617.6
C 26 :	Nonacosane	149	2261.9	2266.3
C 27 :	1-Tetradecanol	149	892.8	2918.9
C 28 :	Tetradecanal	149	6396.8	17814.2
C 29 :	Acetic acid	149	40532.3	43318.7
C 30 :	2,3-Octanedione	149	31448.3	79961.8
C 31 :	1-Heptanol	149	12266.9	21800.3
C 32 :	Hentriacontane	149	1776.4	4007.9
C 33 :	Thiobis-methane	149	5494.6	11816.9
C 34 :	2-Propanone	149	46029.2	58884.7
C 35 :	3-(methylthio)-propanal	149	2421.7	5459.3
C 36 :	1-Octen-3-ol	149	8330.0	26241.6
C 38 :	Pentadecane	149	1658.9	5791.6
C 39 :	(E)-2-Decenal	149	8974.9	18453.3

Table 12. Continued.

Code:	Volatile, Aromatic Chemical	n	Mean	Standard Deviation
C 40 :	Octacosane	149	1745.1	2851.9
C 42 :	1-phenyl-ethanone	149	3641.0	12631.7
C 43 :	(E)-2-Nonenal	149	7520.8	12612.5
C 44 :	1-(1H-pyrrol-2-yl)-ethanone	149	3318.2	10346.8
C 45 :	3-ethyl-2,5-dimethyl-pyrazine	149	5134.1	21410.3
C 46 :	5-Amino-isoxazole	149	95.8	364.2
C 47 :	1,3-Octadiene	149	10204.2	25114.5
C 48 :	Acetophenone	149	441.8	2450.6
C 49 :	2,4-bis(1,1-dimethylethyl)-phenol	149	301.0	975.2
C 50 :	2-Pentanone	149	15474.7	49694.6
C 51 :	Sulfur dioxide	149	1975.4	11940.5
C 52 :	(E)-2-Heptenal	149	3707.6	11022.1
C 53 :	3-methyl-2-butanone	149	10116.0	33754.3
C 54 :	Nonanoic acid	149	1956.0	6717.9
C 55 :	Methanethiol	149	1616.4	6151.6
C 56 :	3-(3-Carboxy-4-hydroxyphenyl) -D-alanine	149	409.1	2404.4
C 57 :	Heptanoic acid	149	4344.2	9310.6
C 58 :	2-(ethenyloxy)-propane	149	2689.5	10991.2
C 59 :	1-Hexanol	149	961.5	6190.2
C 60 :	3-(Hydroxyphenylmethyl) -2-methyl-3-buten-1-ol	149	339.2	1446.2
C 61 :	2-Furan-carboxaldehyde	149	522.7	1935.4
C 62 :	1-Octen-3-ol	149	16287.7	35575.1
C 64 :	1-Decene	149	1756.9	9841.1
C 65 :	2-ethyl-6-methyl-pyrazine	149	2883.8	16101.8
C 66 :	1-Propanol	149	2297.3	7798.9
C 67 :	1-Octene	149	268.7	2295.4
C 68 :	3-methyl-1-butanol	149	361.9	1480.4
C 69 :	2-ethyl-3-methyl-pyrazine	149	872.8	3430.5
C 70 :	1-methyl-4-(1-methylethyl)-benzene	149	5419.4	20267.2
C 71 :	Pentane	149	570.1	4032.8
C 72 :	Dimethyl disulfide	149	9637.4	44889.1
C 73 :	Pentanoic acid	149	1255.8	4064.0
C 74 :	2-Acetyl-2-thiazoline	149	458.4	2250.2
C 75 :	3-Methyl-2-thiophenecarboxaldehyde	149	606.9	2595.8
C 76 :	2-Nonanone	149	1928.7	6327.4

Table 12. Continued.

Code:	Volatile, Aromatic Chemical	n	Mean	Standard Deviation
C 77 :	Hexanoic acid,butylester	149	1375.5	4394.8
C 78 :	2-Ethoxy-1-propene	149	4030.2	31684.3
C 79 :	6,10-dimethyl-2-undecanone	149	675.8	2201.0
C 80 :	Acetic acid	149	5555.5	24371.1
C 81 :	1-methyl-4-(1-methylethenyl)-benzene	149	3096.3	20530.3
C 82 :	Hexanoic acid,pentylester	149	1250.8	4625.1
C 83 :	Eicosane	149	1074.6	5054.3
C 84 :	N,N'-Nonamethylenebis [-S-3-aminopropylthiosulfuricacid]	149	1481.9	12499.2
C 85 :	1-methyl-3-(1-methylethyl)-benzene	149	1121.5	5944.1
C 87 :	Sulfur dioxide	149	15.8	127.1
C 88 :	OctanoicAcid	149	1219.1	5628.2
C 89 :	1,2,4-Triazolo[4,3-a]pyridine	149	132.7	681.6
C 90 :	(1-methylethyl)- methyl benzene,	149	142.1	788.0
C 91 :	(Z)-2-Dodecene	149	612.2	4351.4
C 92 :	1-butyl-cyclohexene	149	464.8	2315.0
C 93 :	2,3-Dimethyl-benzaldehyde	149	144.6	1428.3
C 94 :	1,1'-oxybis-heptane	149	2383.7	12702.9
C 95 :	4-Octen-3-one	149	311.7	1900.1
C 96 :	3-Methyl-2-butanone	149	2410.9	17120.0
C 97 :	3-methyl-nonacosane	149	50.9	363.1
C 98 :	Octadecane	149	1018.9	4146.4
C 99 :	Tridecanal	149	565.7	4214.1
C 100:	2-Undecanone	149	209.0	1265.8
C 101:	1,2-d2-Decane	149	231.4	1602.0
C 102:	N-(methylthio)carbonyl-oxamide	149	57.1	435.3
C 103:	1-Dodecanol	149	272.9	2099.1
C 104:	9-methyl- (Z)-4-undecene	149	37.0	451.8
C 105:	1-Hexadecanol	149	331.5	2334.8
C 106:	1-Heptanol	149	174.0	2123.4
C 107:	1-Tetradecene	149	39.1	477.0
C 108:	2-methyl-2-hydroxy-propanoic acid	149	1944.3	15567.5
C 109:	4,6-dimethyl-pyrimidine	149	160.4	1180.4
C 110:	1-methyl-2-(2-propenyl)-benzene	149	668.9	5773.3
C 111:	N-ethyl-ethanamine,	149	30.8	375.8
C 112:	1-ethyl-2-methyl-cyclopentane	149	55.8	681.4
C 113:	2-(aminooxy)-propanoic acid,	149	27.4	258.1

Table 12. Continued.

Code:	Volatile, Aromatic Chemical	n	Mean	Standard Deviation
C 114:	1-Octanol	149	80.0	976.8
C 115:	N-Hydroxymethyl-2-phenylacetamide	149	187.9	1615.9
C 117:	1-Tridecene	149	22.4	273.5
C 118:	1-Dodecene	149	44.3	540.5

GC/MS Gas Chromatography Mass Spectrometry

Table 13. Least squares means for categories of volatile flavor chemical compounds for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	LMRP	LLDP	LLDP: LMRP	Sulfur-Containing	Nitrogen-Containing	Aldehydes	Alcohols
P – value[e]	0.001	0.06	0.34	<0.001	0.03	0.02	0.054
Choice GM steaks							
GF, 58 °C	650296.6[ab]	4163251.1	6.9	11418.3[bc]	1884.5[b]	3356328.3[ab]	271225.0
GF, 80 °C	833797.7[ab]	3212917.4	4.1	39070.9[bc]	2448.6[b]	2923831.2[bc]	173870.6
Grill, 58 °C	539328.6[ab]	2913876.7	11.1	24635.1[bc]	14363.9[b]	2417579.0[bc]	214582.3
Grill, 80 °C	694947.9[ab]	2368789.1	6.2	43121.7[b]	49942.5[a]	1839756.0[bc]	178390.8
Choice BF roasts							
CP, 58 °C	504093.9[b]	4085166.8	64.5	763.8[bc]	29727.4[b]	3000208.6[b]	181974.5
CP, 80 °C	809657.3[ab]	2170508.9	4.3	1614.3[b]	37254.7[b]	2265588.8[bc]	72282.5
Select BF roasts							
CP, 58 °C	471114.7[b]	2721144.0	29.2	12451.5[bc]	4233.8[b]	2629102.5[bc]	94249.1
CP, 80 °C	847300.4[a]	5087540.2	8.6	106317.0[a]	12420.4[b]	4877750.8[a]	122466.4

Table 13. Continued.

Effect	LMRP	LLDP	LLDP: LMRP	Sulfur-Containing	Nitrogen-Containing	Aldehydes	Alcohols
Choice LM steaks							
GF, 58 °C	681240.3[ab]	2835703.6	4.6	12220.1[bc]	463.1[b]	2313851.9[bc]	187082.5
GF, 80 °C	528496.1[ab]	2550399.5	13.6	9461.4[bc]	25638.0[ab]	2043193.1[bc]	179638.9
Grill, 58 °C	418777.1[b]	2481205.8	9.7	8441.1[bc]	12689.8[b]	1768057.7[bc]	203412.6
Grill, 80 °C	336561.0[b]	2216713.2	6.8	8645.4[bc]	15300.2[b]	2008686.3[bc]	155209.6
High pH LM steaks							
GF, 58 °C	169349.7[b]	1702800.9	11.1	1040.8[c]	455.9[b]	1262960.8[bc]	153979.7
GF, 80 °C	269365.8[b]	2111382.2	15.0	2103.2[c]	116.6[b]	1710147.0[bc]	122366.9
Grill, 58 °C	369919.2[b]	2323923.0	12.6	421.1[c]	6349.4[b]	1090322.9[c]	326748.6
Grill, 80 °C	299118.7[b]	1750122.6	9.9	2507.0[c]	3813.5[b]	1218987.2[bc]	200808.2
RMSE[d]	395958.1	2228636.0	44.0	45756.8	29074.2	2119436.0	147643.9

Table 13. Continued.

Effect	Ketones	Acids	Alkanes	Alkenes	Furans	Pyrazines	Benzenes
P – value[e]	0.02	0.004	0.52	0.49	0.31	0.16	<0.001
Choice GM steaks							
GF, 58 °C	501162.8[b]	163997.1[ab]	292300.0	209207.0	42327.3	1015.1	453657.1[b]
GF, 80 °C	620406.4[ab]	166706.4[ab]	31359.3	96407.1	30597.4	584.2	747249.0[a]
Grill, 58 °C	536914.7[b]	143300.3[ab]	75313.4	47823.9	19454.7	4838.0	479248.0[ab]
Grill, 80 °C	688590.5[ab]	164285.2[ab]	61540.8	107604.3	20571.6	49159.9	539677.6[ab]
Choice BF roasts							
CP, 58 °C	949232.9[a]	174165.0[ab]	109996.6	128145.5	19704.1	0.0	358156.1[bc]
CP, 80 °C	466943.8[b]	89890.4[b]	46353.9	30857.5	17637.8	1736.8	733428.8[ab]
Select BF roasts							
CP, 58 °C	249555.2[b]	65760.6[b]	95092.6	35759.7	32017.4	4158.2	403013.3[bc]
CP, 80 °C	567787.5[b]	106887.6[ab]	56678.8	66310.0	28495.6	10246.5	655775.6[ab]

Table 13. Continued.

Effect	Ketones	Acids	Alkanes	Alkenes	Furans	Pyrazines	Benzenes
Choice LM steaks							
GF, 58 °C	643849.8^{ab}	164486.8^{ab}	74653.0	46292.8	65373.3	281.5	601871.0^{ab}
GF, 80 °C	493129.4^{b}	138880.8^{ab}	38986.0	94225.6	24050.4	34369.3	366007.5^{bc}
Grill, 58 °C	576224.6^{ab}	198078.7^{a}	47555.1	73273.1	22961.9	10489.0	359175.7^{bc}
Grill, 80 °C	220473.9^{b}	82388.4^{b}	39039.2	40447.0	13666.9	13853.4	273951.3^{bc}
High pH LM steaks							
GF, 58 °C	286443.0^{b}	24207.3^{b}	83376.2	98336.5	5868.4	217.5	112368.4^{c}
GF, 80 °C	359465.3^{b}	78410.8^{b}	36696.4	100660.6	16047.7	479.6	211189.0^{bc}
Grill, 58 °C	730610.4^{ab}	94853.8^{b}	193209.8	221306.0	15457.8	7461.7	138636.2^{c}
Grill, 80 °C	363707.7^{b}	45685.4^{b}	93852.2	143532.0	6578.2	4647.8	165612.7^{b}

Table 13. Continued.

Effect	Ring Structure	Straight Compound
P – value[e]	0.2885	0.0493
Choice GM steaks		
GF, 58 °C	218926.9	4177350.6[ab]
GF, 80 °C	103188.7	3251932.3[ab]
Grill, 58 °C	58662.1	2940171.0[b]
Grill, 80 °C	143969.3	2439118.2[b]
Choice BF roasts		
CP, 58 °C	168405.5	4108085.5[ab]
CP, 80 °C	34262.4	2222917.6[b]
Select BF roasts		
CP, 58 °C	65728.3	2739454.9[b]
CP, 80 °C	113305.6	5202737.7[a]

Table 13. Continued.

Effect	Ring Structure	Straight Compound
Choice LM steaks		
GF, 58 °C	101047.4	2856688.1[b]
GF, 80 °C	191610.9	2560757.4[b]
Grill, 58 °C	74604.6	2511708.7[b]
Grill, 80 °C	61164.6	2227044.9[b]
High pH LM steaks		
GF, 58 °C	73733.8	1701150.2[b]
GF, 80 °C	78005.7	2114509.8[b]
Grill, 58 °C	276414.0	2354633.2[b]
Grill, 80 °C	157025.5	1766476.6[b]
RMSE[d]	187902.0	2227291.0

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error.
[e] *P* - value from analysis of variance tables.
LMRP Likely Maillard Reaction Products
LLDP Likely Lipid Degradation Products
LLDP:LMRP Ratio of Likely Lipid Degradation Products to Likely Maillard Reaction products
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 14. Stepwise linear regression for prediction of consumer overall liking as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[b] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	63,221.5		0.55
C 1 :	dioxime ethanedial	-224.31	0.0212	
C 7 :	Nonanal	-0.7497	0.0177	
C 11 :	2,3-Butanedione	-1.88	0.0585	
C 18 :	dl-Limonene	-1.52	0.0086	
C 19 :	1-Octanol	10.61	0.0119	
C 26 :	Nonacosane	-142.32	0.0516	
C 44 :	1-(1H-pyrrol-2-yl)-ethanone	25.03	0.0472	
C 53 :	3-methyl-2-butanone	-4.24	0.0070	
C 55 :	Methanethiol	-35.95	0.0872	
C 69 :	2-ethyl-3-methyl-pyrazine	101.62	0.0484	
C 74 :	2-Acetyl-2-thiazoline	55.96	0.0152	
C 83 :	Eicosane	-27.98	0.0126	
C 85 :	1-methyl-3-(1-methylethyl)-benzene	24.24	0.0107	
C 94 :	1,1'-oxybis-heptane	11.10	0.0586	
C 95 :	4-Octen-3-one	64.26	0.0105	
C 96 :	3-methyl-2-butanone	6.39	0.0106	
C100 :	2-Undecanone	160.44	0.0135	
C102 :	N-(methylthio)carbonyl-oxamide,	-242.94	0.0088	
C105 :	1-Hexadecanol	-52.93	0.0103	
C109 :	4,6-dimethyl-pyrimidine	-120.52	0.0147	
C113 :	2-(aminooxy)-propanoic acid	-464.49	0.0125	
C118 :	1-Dodecene	170.68	0.0100	

[a] Estimates are the b-values for the final regression equation when the defined variable was included.

Table 15. Least squares means for volatile chemicals related to consumer overall liking for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C55 Methanethiol	C26 Nonacosane	C11 2,3-Butanedione	C94 1,1'-oxybis-heptane	C44 1-(1H-pyrrol-2-yl)-ethanone	C69 2-ethyl-3-methyl-Pyrazine
P – value[e]	<0.001	0.54	0.23	<0.001	<0.001	0.67
Choice GM steaks						
GF, 58 °C	0.0[b]	2525.1	103975.6	0.0[b]	112.5[bc]	147
GF, 80 °C	378.1[b]	2411.9	84413.6	0.0[b]	787.5[bc]	321.6
Grill, 58 °C	0.0[b]	2308.9	66373.9	27661.3[a]	8902.7[b]	2379.3
Grill, 80 °C	2050.2[b]	1697.8	113356.8	0.0[b]	21856.0[a]	1145.7
Choice BF roasts						
CP, 58 °C	0.0[b]	2467.2	178484.8	0.0[b]	0.0[c]	0.0
CP, 80 °C	9317.9[a]	2950.2	81808.1	0.0[b]	818.9[bc]	1269.4
Select BF roasts						
CP, 58 °C	3139.9[b]	3891.5	20325	0.0[b]	1038.1[bc]	0.0
CP, 80 °C	8398.3[a]	3047	111585.6	0.0[b]	0.0[c]	147

Table 15. Continued.

Effect	C55 Methanethiol	C26 Nonacosane	C11 2,3-Butanedione	C94 1,1'-oxybis-heptane	C44 1-(1H-pyrrol-2-yl)-ethanone	C69 2-ethyl-3-methyl-Pyrazine
Choice LM steaks						
GF, 58 °C	1000.4[b]	2276.3	52563.9	4079.5[b]	181.6[bc]	0.0
GF, 80 °C	0.0[b]	2051.6	45951.3	0.0[b]	6608.3[bc]	1293.5
Grill, 58 °C	0.0[b]	1291.2	22981.0	9224.1[b]	5100.6[bc]	3264.4
Grill, 80 °C	0.0[b]	933.6	2642.3	0.0[b]	8172.9[bc]	256.1
High pH LM steaks						
GF, 58 °C	0.0[b]	2393.0	28628.2	0.0[b]	161.6[bc]	217.5
GF, 80 °C	0.0[b]	2033.8	75327.2	0.0[b]	116.6[bc]	479.6
Grill, 58 °C	0.0[b]	2333.0	83865.7	0.0[b]	171.9[bc]	2651.2
Grill, 80 °C	0.0[b]	1580.0	2281.4	0.0[b]	0.0[c]	834.3
RMSE[d]	5685.1	2274.9	130164.8	11135.5	9078.5	3476.2

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error.
[e] P - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 16. Stepwise linear regression for prediction of beef flavor identity as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation[b] R^2
	Intercept	104,359.9		0.36
C 9 :	Hexanoic acid	1.32	0.0141	
C 19 :	1-Octanol	3.64	0.0127	
C 22 :	Nonenal	5.81	0.0149	
C 25 :	Tridecanal	19.39	0.0231	
C 30 :	2,3-Octanedione	1.16	0.0275	
C 32 :	Hentriacontane	25.31	0.0134	
C 39 :	(E)-2-Decenal	8.05	0.0215	
C 40 :	Octacosane	34.16	0.0250	
C 51 :	Sulfur dioxide	7.59	0.0455	
C 56 :	3-(3-Carboxy-4-hydroxyphenyl)-D-alanine	39.72	0.0123	
C 59 :	1-Hexanol	20.50	0.0097	
C 61 :	2-Furan carboxaldehyde	48.50	0.0173	
C 64 :	1-Decene	10.12	0.0100	
C 74 :	2-Acetyl-2-thiazoline	45.43	0.0103	
C 82 :	Hexanoicacid,pentylester	22.24	0.0172	
C 97 :	3-methyl-nonacosane	252.62	0.0186	
C 99 :	Tridecanal	25.86	0.0099	
C 100:	2-Undecanone	72.11	0.0199	
C 108:	2-methyl-2-hydroxy-propanoic acid	7.87	0.0094	
C 111:	N-ethyl-ethanamine,	561.21	0.0433	
C 118:	1-Dodecene	167.46	0.0218	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 17. Least squares means for the volatile chemical related to trained descriptive panel attribute beef flavor for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C51 Sulfur dioxide
P – value[a]	0.2384
Ch GM steaks	
GF, 58 °C	0.0
GF, 80 °C	1635.0
Grill, 58 °C	0.0
Grill, 80 °C	15188.8
Ch BF roasts	
CP, 58 °C	1734.9
CP, 80 °C	1721.7
Se BF roasts	
CP, 58 °C	46.9
CP, 80 °C	9106.6
Ch LM steaks	
GF, 58 °C	0.0
GF, 80 °C	0.0
Grill, 58 °C	0.0
Grill, 80 °C	0.0
High pH LM steaks	
GF, 58 °C	0.0
GF, 80 °C	0.0
Grill, 58 °C	0.0
Grill, 80 °C	0.0
RMSE[b]	11825.7

[a] Root Mean Square Error.
[b] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill

Table 18. Stepwise linear regression for prediction of brown/roasted as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	10,658.8		0.32
C 100:	2-Undecanone	128.86	0.0324	
C 26 :	Nonacosane	-59.58	0.0224	
C 44 :	1-(1H-pyrrol-2-yl)-ethanone	30.13	0.0884	
C 65 :	2-ethyl-6-methyl-pyrazine	-11.59	0.0357	
C 68 :	3-methyl-1-Butanol	122.38	0.0255	
C 71 :	Pentane	-27.94	0.0137	
C 74 :	2-Acetyl-2-thiazoline	96.13	0.0306	
C 85 :	1-methyl-3-(1-methylethyl)-benzene	16.10	0.0121	
C 87 :	Sulfur dioxide	853.81	0.0155	
C 97 :	3-methyl-nonacosane	573.37	0.0416	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 19. Least squares means for the volatile chemical related to trained descriptive panel attribute brown/roasted for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C44 1-(1H-pyrrol-2-yl)-ethanone	C97 3-methyl-nonacosane
P – value[d]	<0.001	0.07
Choice GM steaks		
GF, 58 °C	112.5[bc]	0.0
GF, 80 °C	787.5[bc]	0.0
Grill, 58 °C	8902.7[b]	0.0
Grill, 80 °C	21856.0[a]	209.0
Choice BF roasts		
CP, 58 °C	0.0[c]	0.0
CP, 80 °C	818.9[bc]	0.0
Select BF roasts		
CP, 58 °C	1038.1[bc]	0.0
CP, 80 °C	0.0[c]	0.0
Choice LM steaks		
GF, 58 °C	181.6[bc]	0.0
GF, 80 °C	6608.3[bc]	0.0
Grill, 58 °C	5100.6[bc]	0.0
Grill, 80 °C	8172.9[bc]	0.0
High pH LM steaks		
GF, 58 °C	161.6[bc]	0.0
GF, 80 °C	116.6[bc]	0.0
Grill, 58 °C	171.9[bc]	0.0
Grill, 80 °C	0.0[c]	549.0
RMSE[e]	11825.7	378.8

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[e] Root Mean Square Error.
[d] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 20. Stepwise linear regression for prediction of bloody/serumy as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	18,775.1		0.33
C 13 :	1-Butanol	-0.8416	0.0144	
C 19 :	1-Octanol	8.00	0.0372	
C 24 :	Dodecanal	-11.14	0.0189	
C 32 :	Hentriacontane	-33.74	0.0175	
C 40 :	Octacosane	35.94	0.0142	
C 60 :	3-(Hydroxyphenylmethyl)-2-methyl-3-buten-1-ol	-89.23	0.0125	
C 61 :	2-Furan carboxaldehyde	99.31	0.0332	
C 64 :	1-Decene	18.75	0.0264	
C 68 :	3-methyl-1-Butanol	-87.72	0.0185	
C 72 :	Dimethyl disulfide	-3.21	0.0460	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 21. Least squares means for the volatile chemical related to trained descriptive panel attribute bloody/serumy for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C72 Disulfide,dimethyl	C97 Nonacosane,3-methyl-
P – value[c]	0.0331	0.0672
Choice GM steaks		
GF, 58 °C	0.0[b]	23767.0
GF, 80 °C	25662.0[b]	7995.6
Grill, 58 °C	0.0[b]	29083.3
Grill, 80 °C	13502.9[b]	8458.0
Choice BF roasts		
CP, 58 °C	2098.2[b]	6389.4
CP, 80 °C	20772.1[b]	1464.7
Select BF roasts		
CP, 58 °C	0.0[b]	11105.0
CP, 80 °C	72497.5[a]	722.1
Choice LM steaks		
GF, 58 °C	8353.3[b]	34113.0
GF, 80 °C	1115.0[b]	4663.9
Grill, 58 °C	0.0[b]	15894.4
Grill, 80 °C	176.6[b]	9648.9
High pH LM steaks		
GF, 58 °C	0.0[b]	17189.5
GF, 80 °C	1478.6[b]	13026.2
Grill, 58 °C	0.0[b]	9051.9
Grill, 80 °C	0.0[b]	15293.9
RMSE[d]	43182.9	21152.5

[a,b] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error.
[c] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 22. Stepwise linear regression for prediction of descriptive sensory fat-like flavor as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	13,940.4		0.31
C 5 :	Octanal	-0.3634	0.0150	
C 6 :	Benzaldehyde	-0.317	0.0809	
C 9 :	Hexanoic acid	-1.32	0.0218	
C 16:	1-Hexanol	2.02	0.0142	
C 33:	Thiobis-methane	-5.66	0.0398	
C 42:	1-phenyl-ethanone	3.33	0.0104	
C 64:	1-Decene	5.51	0.0124	
C 72:	dimethyl disulfide	-1.55	0.0198	
C 78:	2-Ethoxy-1-propene	2.10	0.0345	
C 87:	Sulfur dioxide	311.81	0.0103	
C 94:	1,1'-oxybis-heptane	6.02	0.0215	

[a] Estimates are the b-values for the final regression equation when the definable was included and variables are not listed in the order that they entered the equation.

Table 23. Least squares means for the volatile chemical related to trained descriptive panel attribute fat-like for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C6 Benzaldehyde	C33 Thiobis-Methane,
P – value[d]	<0.001	0.0018
Choice GM steaks		
GF, 58 °C	422712.6[b]	8283.1[ab]
GF, 80 °C	692665.5[a]	8302.8[ab]
Grill, 58 °C	460365.6[ab]	14679.4[ab]
Grill, 80 °C	511971.7[ab]	7727.9[ab]
Choice BF roasts		
CP, 58 °C	313588.7[bc]	17344.6[a]
CP, 80 °C	732848.3[a]	7314.0[b]
Select BF roasts		
CP, 58 °C	394540.0[bc]	4464.0[b]
CP, 80 °C	628917.1[ab]	14355.0[b]
Choice LM steaks		
GF, 58 °C	568780.9[ab]	750.3[b]
GF, 80 °C	329044.0[bc]	778.6[b]
Grill, 58 °C	335370.6[bc]	790.2[b]
Grill, 80 °C	267182.1[bc]	671.8[b]
High pH LM steaks		
GF, 58 °C	99060.5[c]	672.0[b]
GF, 80 °C	189443.4[bc]	165.1[b]
Grill, 58 °C	93211.2[c]	0.0[b]
Grill, 80 °C	142852.1[c]	1530.2[b]
RMSE[e]	285263.4	10988.39

[a,b,c] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[e] Root Mean Square Error.
[d] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 24. Stepwise linear regression for prediction of descriptive sensory metallic flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	11,993.7		.31
C 13 :	1-Butanol	-1.36	0.0346	
C 14 :	3-hydroxy-2-butanone	0.35	0.0347	
C 22 :	Nonenal	7.42	0.0467	
C 43 :	(E)-2-Nonenal	6.81	0.0288	
C 64 :	1-Decene	15.58	0.0315	
C 66 :	1-Propanol	12.44	0.0181	
C 71 :	Pentane	24.09	0.0196	
C 98 :	Octadecane	28.02	0.0302	
C 101:	Decane-1,2-d2	71.94	0.0500	
C 110:	1-methyl-2-(2-propenyl)-benzene	23.00	0.0165	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 25. Least squares means for the volatile chemical related to trained descriptive panel attribute metallic for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C22 Nonenal	C101 Decane-1,2-d2
P – value[a]	0.3364	0.5120
Choice GM steaks		
GF, 58 °C	18650.4	0.0
GF, 80 °C	3537.5	0.0
Grill, 58 °C	24941.7	445.6
Grill, 80 °C	9673.7	233.6
Choice BF roasts		
CP, 58 °C	8970.3	785.7
CP, 80 °C	1203.7	0.0
Select BF roasts		
CP, 58 °C	23660.7	0.0
CP, 80 °C	5539.3	0.0
Choice LM steaks		
GF, 58 °C	29016.9	0.0
GF, 80 °C	8364.6	0.0
Grill, 58 °C	16637.6	1997.0
Grill, 80 °C	6604.6	0.0
High pH LM steaks		
GF, 58 °C	3469.5	0.0
GF, 80 °C	4243.6	0.0
Grill, 58 °C	6680.6	319.3
Grill, 80 °C	3585.0	0.0
RMSE[b]	24380.1	1611.5

[a] Root Mean Square Error
[b] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 26. Stepwise linear regression for prediction of descriptive sensory liver flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	722.2		0.24
C 4 :	Heptanal	1.84	0.0212	
C 13 :	1-Butanol	-0.36	0.0242	
C 31 :	1-Heptanol	-2.57	0.0181	
C 34 :	2-Propanone	0.72	0.0131	
C 36 :	1-Octen-3-oL	1.75	0.0160	
C 43 :	(E)-2-Nonenal	6.15	0.0208	
C 56 :	3-(3-Carboxy-4-hydroxyphenyl)-D-alanine	19.83	0.0186	
C 72 :	Dimethyl disulfide	-0.79	0.0135	
C 75 :	3-Methyl-2-thiophene carboxaldehyde	20.03	0.0274	
C 96 :	3-Methyl 2-butanone,	3.60	0.0290	
C 102:	N-(methylthio)carbonyl-oxamide	162.71	0.0240	
C 103:	1-Dodecanol	19.39	0.0159	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 27. Least squares means for the volatile chemical related to trained descriptive panel attribute liver-like for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C4 Heptanal	C30 2,3-Octanedione	C72 Dimethyl, disulfide
P – value[c]	0.7423	0.6954	0.0331
Choice GM steaks			
GF, 58 °C	1086.8	26974.5	0.0[b]
GF, 80 °C	1852.1	26125.3	25662.0[b]
Grill, 58 °C	881.1	12768.1	0.0[b]
Grill, 80 °C	2525.5	19632.7	13502.9[b]
Choice BF roasts			
CP, 58 °C	22442.0	40470.7	2098.2[b]
CP, 80 °C	29836.3	42413.5	20772.1[b]
Select BF roasts			
CP, 58 °C	532.6	9711.4	0.0[b]
CP, 80 °C	4215.3	104416.6	72497.5[a]
Choice LM steaks			
GF, 58 °C	718.9	45034.1	8353.3[b]
GF, 80 °C	1470.4	18208.6	1115.0[b]
Grill, 58 °C	28299.2	26880.7	0.0[b]
Grill, 80 °C	727.7	44975.3	176.6[b]
High pH LM steaks			
GF, 58 °C	583.9	18074.9	0.0[b]
GF, 80 °C	1459.7	20727.6	1478.6[b]
Grill, 58 °C	8933.9	8293.9	0.0[b]
Grill, 80 °C	7543.9	33575.1	0.0[b]
RMSE[d]	36574.3	81127.9	43182.9

[a,b,] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error
[c] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

Table 28. Stepwise linear regression for prediction of descriptive sensory umami flavor attribute as the dependent variable and aromatic volatile compounds as independent variables.

Code:	Volatile, Aromatic Chemical	Estimate[a] x 10^{-6}	Partial R^2	Equation R^2
	Intercept	8,233.0		0.60
C 9 :	Hexanoic acid	1.69	0.0160	
C 15 :	N-Heptanal	-0.26	0.0167	
C 17 :	2-pentyl-furan	-1.55	0.0116	
C 19 :	1-Octanol	-6.05	0.0722	
C 21 :	Phenylacetaldehyde	-9.32	0.0131	
C 22 :	Nonenal	-13.24	0.0091	
C 23 :	1,3-bis(1,1-dimethylethyl)-benzene	-3.11	0.0091	
C 27 :	1-Tetradecanol	-22.87	0.0195	
C 28 :	Tetradecanal	7.93	0.0178	
C 32 :	Hentriacontane	35.24	0.0194	
C 36 :	1-Octen-3-oL	4.29	0.0168	
C 38 :	Pentadecane	-10.63	0.0104	
C 39 :	(E)-2-Decenal	18.03	0.0315	
C 43 :	(E)-2-Nonenal	-10.15	0.0184	
C 51 :	Sulfur dioxide	11.27	0.0499	
C 59 :	1-Hexanol	-14.93	0.0114	
C 61 :	2-Furan carboxaldehyde	-47.15	0.0154	
C 64 :	1-Decene	-13.41	0.0175	
C 69 :	2-ethyl-3-methyl-pyrazine	39.25	0.0172	
C 74 :	2-Acetyl-2-thiazoline	40.54	0.0174	
C 75 :	3-Methyl-2-thiophenecarboxaldehyde	48.84	0.0178	
C 77 :	Hexanoic acid,butyl ester	18.64	0.0096	
C 79 :	6,10-dimethyl-2-undecanone,	40.96	0.0100	
C 82 :	Hexanoic acid, pentyl ester	14.54	0.0426	
C 92 :	1-butyl-cyclohexene	25.24	0.0238	
C 102:	N-(methylthio)carbonyl-oxamide	199.30	0.0472	
C 103:	1-Dodecanol	49.32	0.0098	
C 107:	1-Tetradecene	-150.72	0.0159	
C 108:	2-methyl-2-hydroxy-propanoic acid,	7.52	0.0112	

[a] Estimates are the b-values for the final regression equation when the defined variable was included and variables are not listed in the order that they entered the equation.

Table 29. Least squares means for volatile chemicals related to trained descriptive panel attribute umami for 16 beef cuts, grades, pH and internal temperature endpoint treatments.

Effect	C19 1-Octanol	C51 Sulfur dioxide	C102 N-(methylthio) carbonyl-oxamide,	C82 Hexanoic acid, pentylester
P – value[c]	0.0341	0.2384	0.5707	0.5892
Choice GM steaks				
GF, 58 °C	58053.5[a]	0.0	0.0	131.0
GF, 80 °C	34320.6[ab]	1635.0	127.1	1512.0
Grill, 58 °C	59661.7[a]	0.0	0.0	0.0
Grill, 80 °C	40364.3[ab]	15188.8	0.0	1784.2
Choice BF roasts				
CP, 58 °C	41688.0[ab]	1734.9	423.0	0.0
CP, 80 °C	16552.9[b]	1721.7	0.0	3786.8
Select BF roasts				
CP, 58 °C	23212.8[b]	46.9	0.0	268.3
CP, 80 °C	16373.2[b]	9106.6	0.0	431.5

Table 29. Continued.

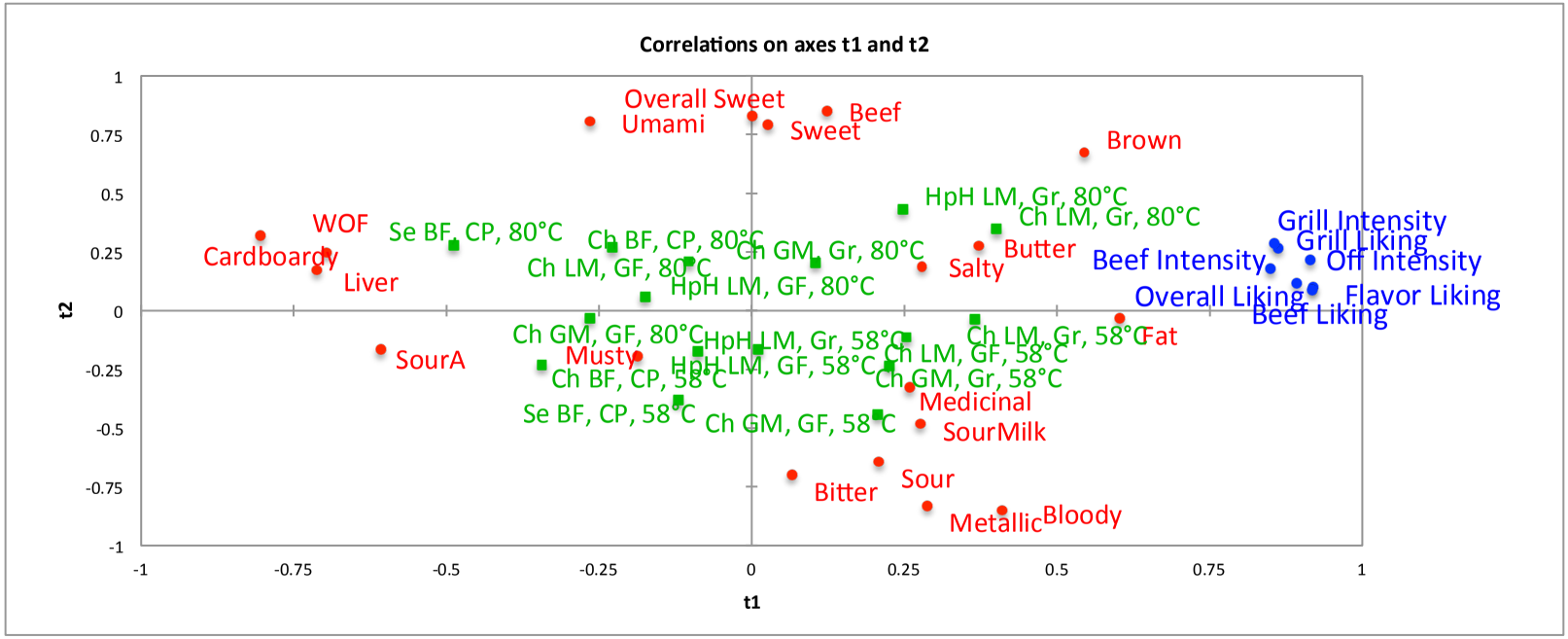
Effect	C19 1-Octanol	C51 Sulfur dioxide	C102 N-(methylthio) carbonyl-oxamide	C82 Hexanoic acid, pentylester
Choice LM steaks				
GF, 58 °C	53271.1[a]	0.0	0.0	4403.1
GF, 80 °C	27483.6[ab]	0.0	375.4	370.8
Grill, 58 °C	38405.9[ab]	0.0	0.0	0.0
Grill, 80 °C	24631.6[b]	0.0	0.0	3539.0
High pH LM steaks				
GF, 58 °C	46743.6[ab]	0.0	0.0	655.9
GF, 80 °C	31488.0[ab]	0.0	0.0	0.0
Grill, 58 °C	57980.0[a]	0.0	0.0	1646.9
Grill, 80 °C	42376.0[ab]	0.0	0.0	1441.6
RMSE[d]	31749.9	11825.7	439.1	4668.7

[a,b] Mean values within a column and effect followed by the same letter are not significantly different ($P > 0.05$).
[d] Root Mean Square Error.
[c] *P* - value from analysis of variance tables.
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
CP Crock Pot

APPENDIX B

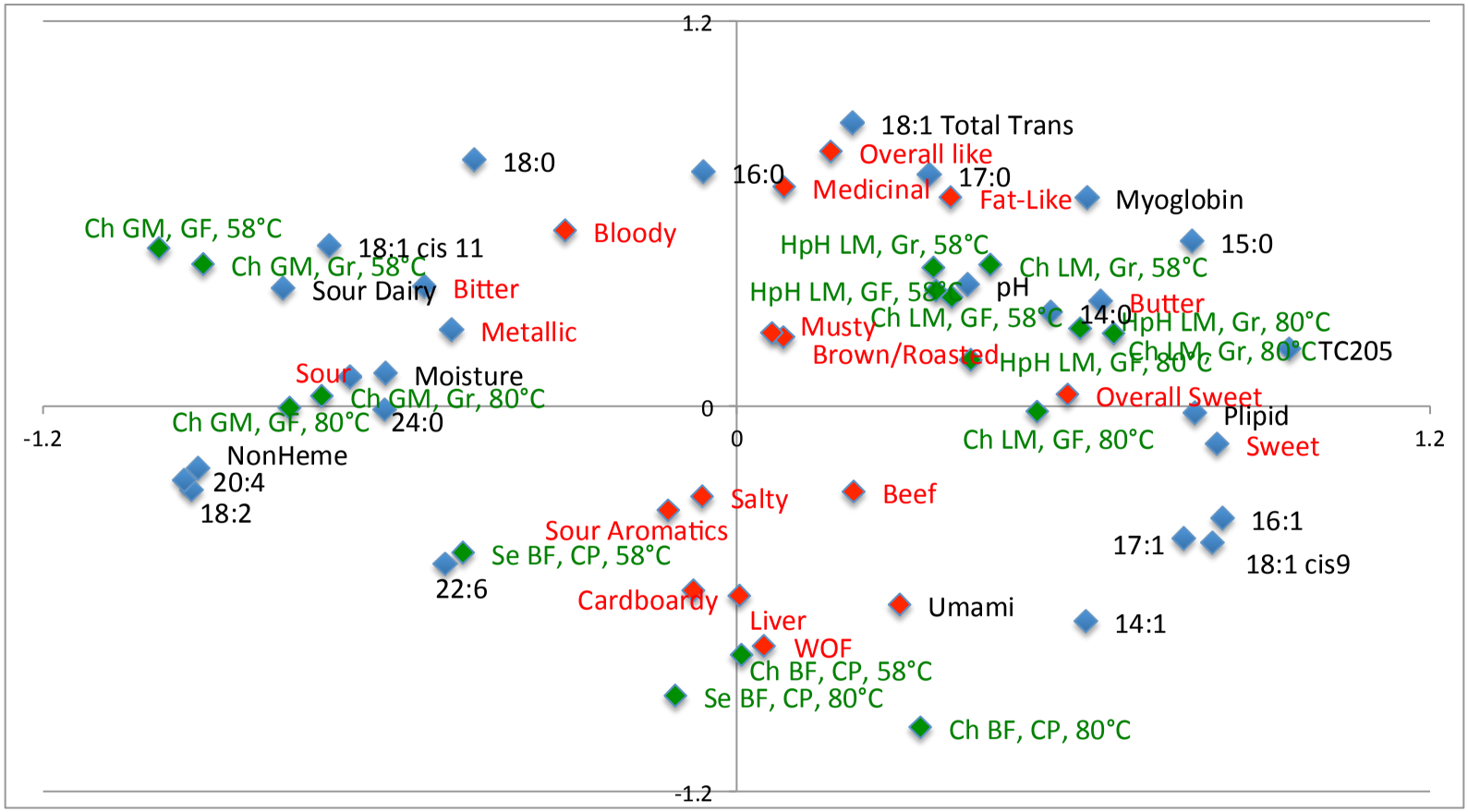
FIGURES

Figure 1. Principal component analysis of trained descriptive flavor attributes, cooking treatments and consumer liking.



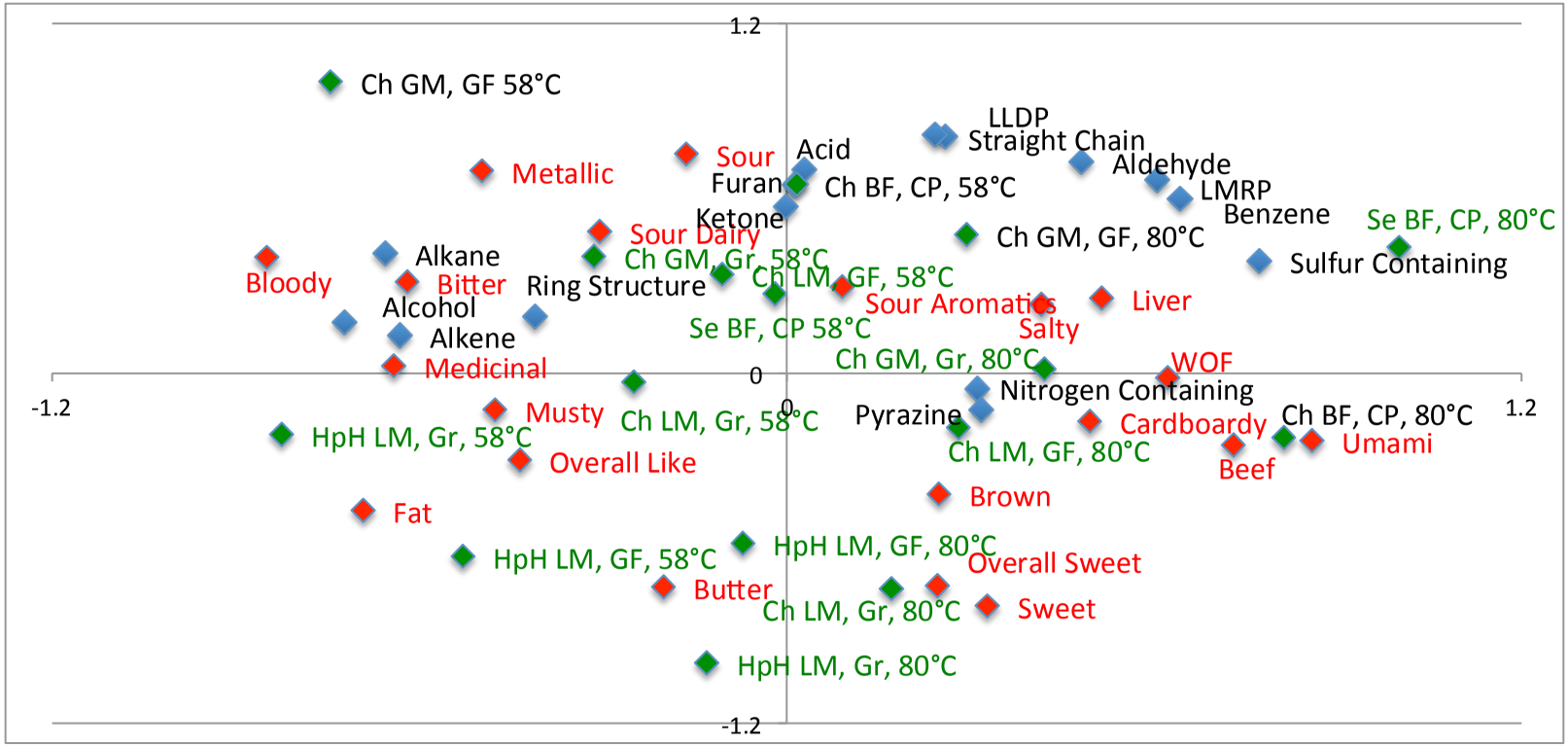
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
GR Grill
CP Crock Pot

Figure 2. Principal component analysis of chemical data, trained descriptive flavor attributes and consumer liking.



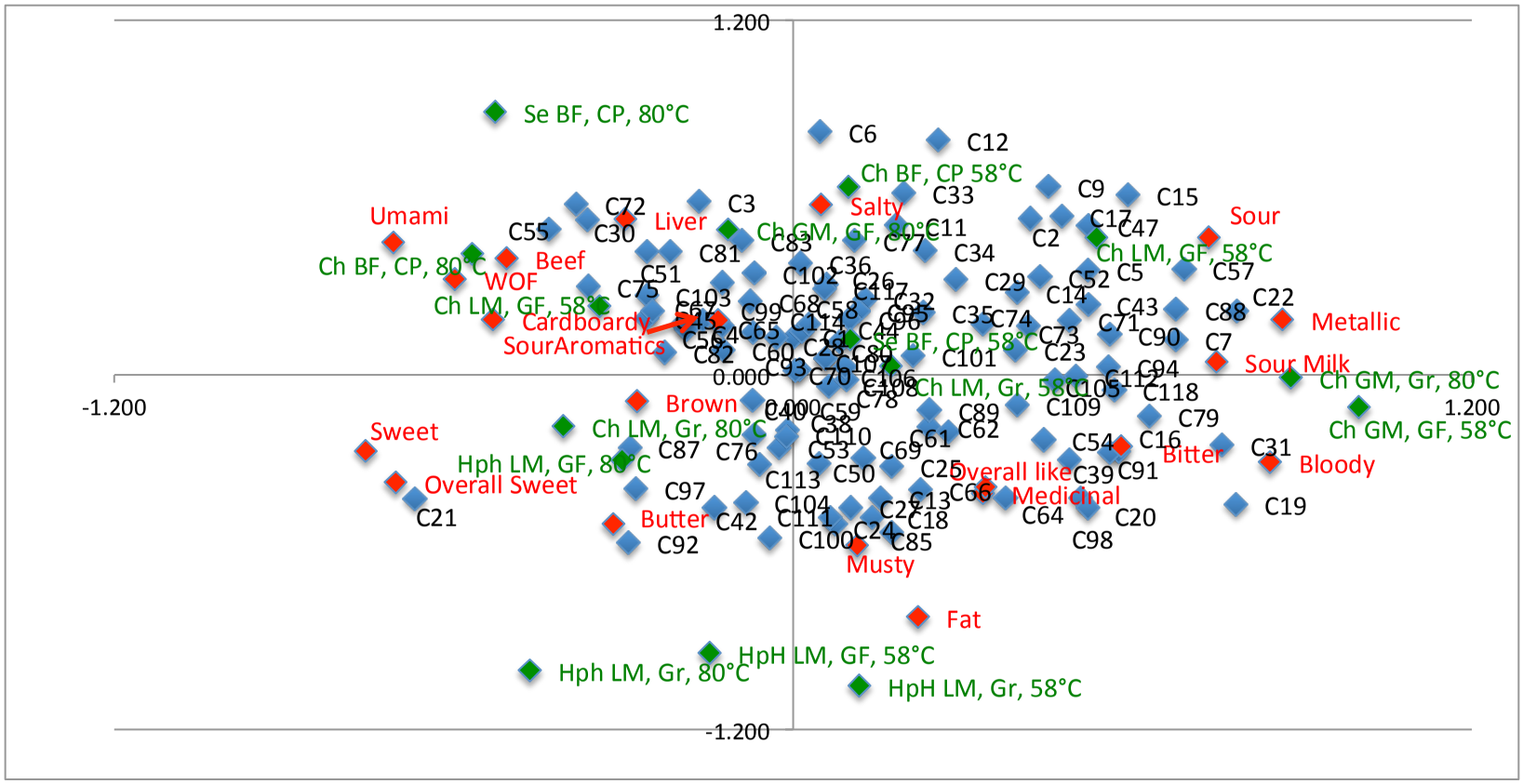
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
GR Grill
CP Crock Pot

Figure 3. Principal component analysis for aromatic chemical compounds categories, cooking treatments, trained descriptive flavor attributes and consumer liking.



LMRP Likely Maillard Reaction Products
LLDP Likely Lipid Degradation Products
GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
GR Grill
CP Crock Pot

Figure 4. Partial least square regression for aromatic chemical compound categories, cooking treatments, trained descriptive flavor attributes and consumer liking.



GM *M. Gluteus medius*
BF *M. Biceps femoris*
LM *M. Longissimus lumborum*
GF George Forman grill
GR Grill
CP Crock Pot